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A smart system to manage the context evolution in the Cultural Heritage domain☆

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ABSTRACT

Nowadays intelligent and pervasive environments are characterized by a great number of devices and sensors that develop continuously and capture enormous amounts of data. Designing a context-aware system able to provide the most tailored services to users according to their behaviors, preferences and needs is still a research challenge. In such environments, although the context is very complex, dynamic and full of data captured and produced, users aspire to automatically receive *contextualized* services. The Cultural Heritage domain represents a domain where exchanged and produced data can be opportunely exploited by a set of applications and services in order to transform a static space into a *smart* environment. In this perspective, this paper presents a context-aware system named Context Evolution System (CES) able to represent and manage the evolution of the context through its instances; such an evolution is driven by occurring events and opportunely modeled by a graph structure. To assess the proposed solution, a Cultural Heritage case study of a real temporary art exhibition named *the Beauty or the Truth* and located in Naples (Italy) is presented and discussed.

1. Introduction

Environments defined as intelligent and pervasive identify places where there is a widespread use of embedded devices, sensors, mobile applications and services. Such an environment enables the creation of a dynamic ecosystem in which a large amount of data is constantly produced and captured. In the last decade, Service-Oriented Architecture (SOA) systems have been widely applied to integrate sensors, devices and software applications [1,2] in this kind of environments. Fully realizing the great potential of all these service-provisioning scenarios, *context-awareness*, defined as the ability to provide services with full awareness of the current execution environment (the context), is widely recognized as one of the key points in the design of modern mobile and ubiquitous systems [3–6]. However, the context and its continuous evolution are essential aspects to be considered if we want to establish which of the available services are the most appropriate to be delivered. The context surrounding a user is rich of information since produced data, and user behaviors, preferences and needs continuously and rapidly changes. When we talk about context and the modeling of its instances, several factors such as location, time, environmental parameters, user behaviors and preferences, and the relationships among context instances should be clearly specified. Modeling the context through its evolution represents a crucial requirement in order to determine a correct context-switch and consequently a dynamic selection of useful data and services. Indeed, a model simplifying

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the manipulation of complex context-aware systems is a crucial need for the specification and analysis of the services. Such a context model allows an explicit representation of the evolution in the context along with the processing flow of context-aware services. Several context modeling approaches [7] such as the key-value, graphical, mark-up scheme, object-oriented, logic-based, and ontology-based models have been studied to specify the acquisition, management, and relationship of context. The pervasive computing research community is constantly appraising the benefits of a formal modeling of context and its evolution, since context modeling can strongly reduce the complexity of context-aware applications [8]. The Cultural Heritage domain and its spaces represent a world wide resource of inestimable value and such a value gains increasing importance when embedded into the digital ecosystem of a Smart City [9]. In particular, it is a domain characterized by a wide public participation; either in a museum, at an art exhibition or in an old town centre the context is represented by people interacting with cultural items and spaces, nowadays equipped with several ICT technologies. In this scenario, people (citizens, tourists, etc.) and objects (buildings, rooms, artefacts, etc.) equipped with appropriate devices (GPS, smartphones, video cameras, sensors, RFID, etc.) give rise to continuous context evolutions in which all the mentioned entities, and others, can produce, communicate and share data.

Nowadays, cultural spaces represents complex environments, in which ICT tools and applications are widespread; people equipped with mobile devices can interact with cultural objects, sharing and producing data, but at the same time they require useful personalized services to enhance the quality of their cultural experience. In this paper we present a smart context-aware system to model the context evolution, adopting a graph structure, named Context Evolution System (CES). In our system, the activation of the most appropriate services to be provided to users is driven by occurring events. Developing *smartness* within this kind of environment means not only introducing innovative and sensing technologies but also transforming the captured data into useful information to deliver customized services to users. Enhancing the quality of a cultural experience depends on different factors; to assess the usability and the user satisfaction, a real case study in the Cultural Heritage domain is presented and discussed. In detail, we show an example of context evolution modeling inside an art exhibition named *The Beauty or The Truth*, located in Naples within the monumental complex of San Domenico Maggiore, Italy. Inside the exhibition spaces, ICT technologies such as sensors and a mobile application are deployed to enable the smartness of this kind of space. The rest of the paper is organized as follows. Section 2 describes the background of the proposed approach and the related works. Section 3 details the CES system with its components. Section 4 details the proposed context evolution model based on a graph approach. Section 5 discusses the case study and the experimental results. Section 6 concludes the paper with some considerations and challenges.

2. Background and related work

The development of advanced services for smart and pervasive environments is still complicated by the high dynamism of the designed systems, which have to deliver meaningful information to users often in real-time, depending on their movements in the physical space, and on their interactions with sensors and devices, and accounting for their past choices and current needs. In particular, useful information for users depends on several parameters such as location, interests, network performance, the semantics of the content, multimedia features, and other context information, and so on. Moreover, it would be useful for a user, when inside this kind of space, to receive a set of the most appropriate services and information in order to navigate the physical space in terms of browsing activities and consequently improve his/her experience.

In this perspective, context-aware computing enables a system to interact with users through devices sensitive to the environment [10,11]. Accordingly, the authors in [12] envisioned scenarios where users would look for relevant POIs by querying services through mobile phones and standard Internet protocols. In 1994, Schilit et al. [13] pioneered the term context-aware pervasive systems. Their work detailed a model of computing in which several diverse mobile and stationary systems interact with the user in order to determine, according to the user's location, POIs and people that are near, as well as changes in those objects over time. In [14], the goal of context-aware computing is to provide relevant information and/or services to the user, where relevancy depends on the user's task. One of the most important criteria in context-awareness system is to efficiently represent the relationships and dependencies among the contexts via well formalized methodologies.

In the last decade, a number of context modeling and reasoning approaches have been developed, ranging from very simple early models to the current state-of-the-art context models. As is well known, the model specifies the acquisition, management, and relationship of the context [7]. The context is characterized as the information that can be used to characterize the situation of an entity [15]. Several types of data gathered by sensors or other devices are captured, interpreted and converted to inferred contexts by a specified rule or algorithm. The context model has to satisfy various requirements [8]; heterogeneity and mobility, relationships and dependencies, timeliness, imperfection, reasoning, the usability of modeling formalisms, and efficient context provisioning.

In a broader sense, the context can be defined as follows: *context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves* [14].

Considering the Cultural Heritage domain, the authors of this paper have already experienced the design and the application of location-based services and technological tools applied to such environments (especially indoors) as reported in [16–19]. Moreover, service discovery in pervasive and smart environments has been addressed in [20,21]. Early discovery approaches were based on the functional description of services, for instance service category, semantic description and key