

# Modelling the context evolution in Cultural Heritage domain: a graph approach

Angelo Chianese  
University of Naples  
"Federico II"

Department of electrical engineering and  
information technology  
angchian@unina.it

Francesco Piccialli  
University of Naples  
"Federico II"

Department of Mathematics and Applications  
"Renato Caccioppoli"  
francesco.piccialli@unina.it

## ABSTRACT

Nowadays, smart and pervasive environments are characterized by a large number of devices and related services offered to users. Providing the most appropriate services according to users behaviour and preferences is still a challenge and strongly depends on the user's current context. How it is well known, the context is often rich of data and very dynamic, and the users aim to continuously receive information about *contextualised* services. In this scenario, Cultural Heritage represents a domain where exchanged and produced data can be opportunely exploited by a set of applications and services in order to make the environment *smart*. This paper proposes a novel approach to represent and manage the evolution of context instances driven by events adopting a graph structure. As a case study, we propose an example of context evolution in an art exhibition within the Maschio Angioino castle, in Naples (Italy).

## Categories and Subject Descriptors

H.5.1 [Information interfaces and presentation]: Multimedia Information Systems; E.1 [Data]: Data Structures—*Graphs and networks*

## General Terms

DESIGN

## 1. INTRODUCTION

Smart and pervasive environments identify places where the widespread use of embedded devices and related provided services enables the creation of a dynamic ecosystem in which a large amount of information is constantly produced and captured. In such environments, Service-Oriented Architecture (SOA) has been widely applied for integrating sensors, devices and software applications [3, 4]. However, the context and its evolution is an essential aspect 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 and changes rapidly; several aspects have to be considered such as location, time, environmental information and so on. Modelling the context evolution represents a crucial task in order to determine a context-switch and consequently a dynamic selection of "useful" data and services. Cultural Heritage represents a world wide resource of inestimable value and such a value gains more and more importance when embedded into the digital ecosystem of a Smart City [5], where several aspects have to be considered at the same time. Indeed, it is a domain characterized by a wide people participation; either in a museum or in an art exhibition or in an old town centre the context is represented by people that interact with cultural items nowadays equipped with several ICT technologies. In this scenario, persons (citizens, tourists, etc.) and objects (buildings, rooms, artefacts, etc.) equipped with appropriate devices (GPS, smartphone, video cameras, sensors, RFID, etc.) give rise to continuous context evolutions in which all the mentioned entities, and more, can communicate, transfer and share knowledge. In this paper we present a novel approach to model the context evolution, adopting a graph structure. The activation of the most appropriate services to be provided to users is driven by events. As a case study, we show an example of context evolution modelling of an art exhibition within the Maschio Angioino castle in Naples. The paper is organized as follows: Section 2 describes a motivating example, Section 3 gives a system architecture overview, Section 4 details the proposed context evolution model, Section 4 shows a case of study and preliminary results and finally Section 6 concludes the paper.

## 2. MOTIVATING EXAMPLE

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 in real-time, depending on their movements in the physical space, on their interactions with smart sensors and devices, and accounting for their past choices and current needs. In particular, in this kind of systems, useful information for users depend on several parameters such as: location, interests, network performance, semantics of the content, multimedia features, other context information, and so on. In addition, it should be useful for a user to receive the set of the most appropriate services for navigating the physical space in terms of browsing activities. As motivating example, we consider the case of a user that intends to visit a sculptures exhibition within the Maschio

Angioino castle, in Naples (Italy), where a set of services and multimedia data, before and during the cultural experience, will be modelled and delivered such as the booking, the ticketing and the multimedia guide services.

### 3. THE SYSTEM OVERVIEW

Figure 1 describes a functional overview of the proposed systems; at a glance, we design a Context Evolution System (CES) that can be seen as composed by the following main components:

- **Services Deliverer:** this module is responsible for services delivering and adaptation to users. For example, when a user is near to a cultural item: (i) its presence will be detected by a deployed sensor (*event*), (ii) the context changes and the Services Deliverer enables the multimedia guide service in order to provide multimedia content of that item to the user.
- **Services Engine:** this component represents the engine responsible for events management and the consequent context switching. It is composed by three modules:
  1. Events Detector: this module captures the events (e.g. a sensor detects a too high temperature value within a museum room, a sensor detects a visitor near a cultural item, a sensor detects an emergency situation, etc.) and enables the context switching computation.
  2. Context Switching Computation: this module, triggered by the Events Detector, is responsible for the context-switch and the dynamic selection of *Contextual Data Views* (useful data) and *Basket of Services* (useful services).
  3. Visiting Paths generation: this module is responsible to arrange cultural items in apposite visiting paths to be provided to users.
- **Knowledge base and User LOG:** these repositories manage respectively multimedia data, in order to propose objects of interest to users arranged in the shape of visiting paths, and captured (by deployed sensors) users behaviour logs.
- **Context Manager:** this module is responsible for managing the current context by storing the overall information (data) that characterizes the context at a given moment.

## 4. DESIGN CONTEXT-AWARE APPLICATIONS BY TAILORING DATA AND SERVICES

### 4.1 The concept of Single Smart Space

We define a Single Smart Space,  $S^3$ , as a big sensor capable of observing the reality in order to facilitate its transfer into the digital world, since it produces represented and stored knowledge. A  $S^3$  must be able to manage:

- the set of sensors that perceive the real world by providing a vision constantly updated of it;

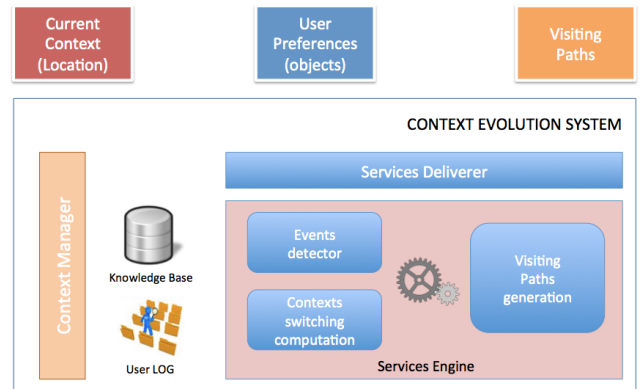


Figure 1: A system overview.

- the set of sources which are useful to the context awareness;
- the monitoring of the reality in order to develop the capacity for intervention based on the produced diagnostics;
- the individuals that interact in the environment;
- the end-users as the set of actions recipients that ensure the sustainability, both in economic terms but also more simply as the perceived quality of life;
- the governance of the space in terms of the possibility of action, aimed at improving the effectiveness and efficiency of interventions;
- the knowledge produced and adequately stored and classified.

The figure 2 summarizes the capabilities of an  $S^3$ , by showing the interactions among the functionalities within the environment. The aim of this kind of space is the developing of such intelligence that is required to transform a cultural site in a smart cultural environment. The overall parameters and services collected and produced by a  $S^3$  can represent, at a given moment, a context instance; they can change and evolve driven by a series of events that trigger context switches.

### 4.2 Services Activation driven by the Context: the Context Evolution Graph

Once we described the features a Single Smart Space ( $S^3$ ), we want to represent the evolution of context instances that in our hypothesis is driven by the *events* that correspond with particular *situations* (e.g. a sensor detects a too high temperature value for a museum room, etc.) and software *services* (e.g. booking a museum visit, using a multimedia guide, etc.). Indeed, the situations' occurrence or services' activation determines a context-switch and at the same time the dynamic selection of "useful" data (*Contextual Data Views*) and services (*Basket of Services*) that can be opportunely exploited as a result of data and service tailoring. In particular, we adopt a graph structure, named *Context Evolution Graph* (CEG), able to model the evolution among

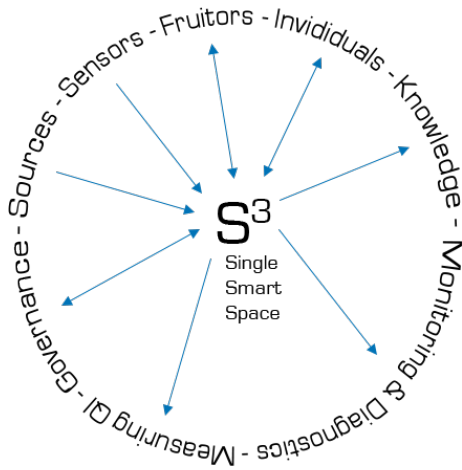


Figure 2: The Single Smart Space -  $S^3$  model.

context instances depending on the situations or services that follow one other in the considered  $S^3$ . Given a set  $C = \{c_1, \dots, c_n\}$  of contexts, a set  $E = \{e_1, \dots, e_m\}$  of events, a set  $S = \{S_1, \dots, S_k\}$  of baskets of services and a set  $V = \{v_1, \dots, v_h\}$  of contextual data views, we can model the context evolution as a labelled graph  $CEG = (C; \Sigma; l_c; l_s)$ , where  $(C, \Sigma)$  is a directed graph,  $l_c : c \in C \rightarrow (v, S)$  is a function that associates each context with the related contextual data view and basket of services and  $l_s : t \in \Sigma \rightarrow e$  is a function that associates each edge in  $\Sigma \subseteq C \times C$  with the particular service (or a services' composition) that can be activated or a given situation that can occur in the current state originating the context-switch. In the case of events corresponding to services' activation, there is a constraint that the activated services have to belong to the Basket of Services related the current context.

In the initial state, no useful contextual data are associated to the user, while only the museum *booking* web service is available. In particular, the web service allows the booking of a visit for a particular date and requires some information about user profile. Once booking a visit for a given date, the next context contains information about the user profile in terms of favourite language, documentation type (images, video, audio) that will be provided by the museum multimedia guide App and of level of expertise; eventually, the *ticketing* service is now enabled. After the activation of the ticketing service, the user can buy the ticket and download the museum mobile application.

The figure 3 summarizes the entire CEG related to a *visitor* for the indoor museum context. In the visiting date, the user can activate the *accounting* service that registers her/his presence inside the museum. At this point, the user can star her/his visit and only a *proximity\_detection* service is now available. The *multimedia guide* service will be activated only if the user device, for example, reads a bar-code related to a picture or a sensor detects its vicinity this item, tailoring her/his preferences; eventually a user can post some feedbacks on the different social networks about her/his experience using the *comment* service. The user by means of multimedia guide service can be driven through the show and watches all the pictures or sculptures of her/his inter-

est. At the end of the visit, the user can terminate his/her experience activating the *exit* service and can choose to save her/his cultural path (observed pictures and the related documentation, etc.) in a digital shape using the *visit saving* service. If during a visit an emergency event occurs, the user has to follow the instructions provided by the *assistant* services (e.g. to reach the most close exit or to change her/his visit path).

The figure 4 shows the context evolution for the indoor museum scenario from the museum supervisor perspective. At the beginning, the museum supervisor can activate the *configuration* service to define the sensor deployment into the museum in terms of types, activation-time and location of sensors. After the deployment, the supervisor can activate the *monitoring* service that gathers all sensed data by the sensors. Successively, it is possible to activate the *event detection* service on the collected data that is able to detect particular emergency situations or situations requiring particular maintenance activities. In both cases, *recovery* services have to be activated to solve the related problems (e.g. an employee can be informed on the maintenance activities to execute or in critical situations all the visitors are encouraged to exit).

## 5. A CASE STUDY AND PRELIMINARY EXPERIMENTAL RESULTS

In this section a case of study of the proposed system is presented and discussed; as real scenario we consider the temporary art exhibition of sculptures within the Maschio Angioino castle, in Naples (Italy), that consists of a few rooms where are placed several cultural items. The cultural environment offers by a Wi-Fi connection a web-based access to a multimedia collection containing: digital reproductions of sculptures by Francesco Jerace and other minor artists, educational videos, audio guides, textual and hypermedia documents with description of authors and sculptures. The user visit starts with a booking and ticketing phases; after these steps the user is walking within the exhibition rooms through several sculptures and when he/she is particularly close to one of them, its mobile device, equipped with a mobile application, is detected by the smart sensor node placed on the item. Once the user mobile device has been detected, the CES captures this event, performs a context switch creating new useful multimedia data and activating the correct available services. The multimedia content (texts, audios, videos and images) of the cultural items related to the case of study are stored in the knowledge database of DATABENC<sup>1</sup>, the high technology district for Cultural Heritage in regione Campania, ITALY.

### 5.1 Implementation Details

In the following, we report some implementation details concerning the developed system, in prototype form. The deployed Wireless Sensor Network component have been realized and tested using the Waspnote and Meshlium models of products offered by Libelium<sup>2</sup> (using Bluetooth devices of Class 1 and 2), but at the moment we have not terminated yet the deployment of the WSN within Maschio Angioino rooms. The CES has been implemented by several JAVA

<sup>1</sup><http://www.databenc.it>, <http://www.databenclab.unina.it>

<sup>2</sup><http://www.libelium.com>

libraries exploiting multi-threading facilities. In addition, communication logs have been stored into a proper repository managed by the Nosql DBMS Cassandra. Moreover, the system exploits ad-hoc JAVA libraries realized in [2] to build the multimedia story of a sculpture and recommend visiting paths, on the of an image collection managed by PostgreSQL DBMS. Finally, a user can interact with our system using a mobile application (see the Figure 5). The client requests are elaborated by JAVA Servlets and the results are sent to the client in form of XML data.



Figure 5: The main screens of the developed mobile application.

## 5.2 Preliminary results

Context awareness systems are generally complex applications that are based on a combination of several models, algorithms and heuristics. Recently, researchers began examining issues related to users’ subjective opinions and developing additional criteria to evaluate these systems. In order to evaluate the impact of the system on the users we have conducted the following experiments. We asked a group of 25 people (all medium experts in art) to visit a virtual reproduction of the exhibit (5 rooms containing the collection of sculptures) obtained by the *Unity 3D* framework and complete several browsing tasks (15 tasks per user) of different complexity (i.e. *Low Complexity* tasks - Q1, *Medium Complexity* tasks - Q2, *High Complexity* tasks - Q3) without the help of our system. After this test, we asked them to browse once again the same collection with the assistance of our system and complete other 15 different tasks of the same complexity. Each task consists in exploring a certain number of sculptures satisfying several constraints. The complexity of a task depends on several factors: the number of objects to explore, the type of desired features (either low or high-level), and the number of constraints (genre, author, subject).

A simple strategy has been used to evaluate the results of this experiment: empirical measurements of access complexity in terms of number of virtual rooms and time. In particular, we measured the following parameters: (i) *Access Time* ( $t_a$ ) - the average time spent by the users to visit all the objects for a given class of tasks; (ii) *Number of Rooms* ( $n_r$ ) - the average number of visited virtual rooms necessary to visit all the requested objects for a given class of tasks. Table 1 reports the average values of  $t_a$  and  $n_r$ , for both without and with the help of our system, for each of the four task complexity levels defined earlier.

## 6. RELATED WORK

In the last decade, a number of context modelling and reasoning approaches have been developed, ranging from very simple early models to the current state-of-the-art context models. In 2004, the authors in [10] envisioned scenarios

Table 1: Comparison between our system and no facilities

| Task Class | Strategy         | $t_a$ (min) | $n_r$ |
|------------|------------------|-------------|-------|
| Q1         | Without any help | 6.3         | 4     |
| Q1         | Our System       | 4.7         | 2     |
| Q2         | Without any help | 9.1         | 5     |
| Q2         | Our System       | 5.2         | 3     |
| Q3         | Without any help | 15.1        | 6     |
| Q4         | Our System       | 9.3         | 4     |

where users would have looked for relevant POIs by querying services through mobile phones and standard Internet protocols. In 1994, [11] 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 users location, POIs and people that are near, as well as changes in those objects over time. In the last years, the authors of this paper have experienced the design and the application of location-based services and technological tools applied to Cultural Heritage environments (especially indoor), in [7, 8, 6, 9]. Indeed, service discovery in pervasive and smart environments has been addressed in recent years [12, 13]. Early discovery approaches were based on the functional description of services, for instance service category, semantic description and key words. These prototypes aimed to transfer a *smartness* to cultural sites, applying different communication technologies and sensors. The proposed Context Evolution System aims to enrich the Cultural Heritage platform developed in our previous works, in order to enhance user cultural experience and satisfaction during museums and art exhibition visits.

## 7. CONCLUSIONS

In this paper, we have presented a new approach to manage the evolution of context instances that is driven by events, adopting a graph structure named Context Evolution Graph. The proposed system is able to detect an occurred event, performing a context switch and providing useful data and services to the users. The key features of the proposed approach are: it exploits an event-driven methodology to change the context data views and basket of services, (ii) it establishes a new context evolution model by using a graph structure. Then, we investigated the effectiveness of the proposed approach in the considered scenario, based on several parameters. Preliminary experimental results showed that our approach is quite promising and encourages further research. Future work will be devoted to collect more complete and interesting experimental results about the real advantages of the proposed technology also considering the related cost and benefits.

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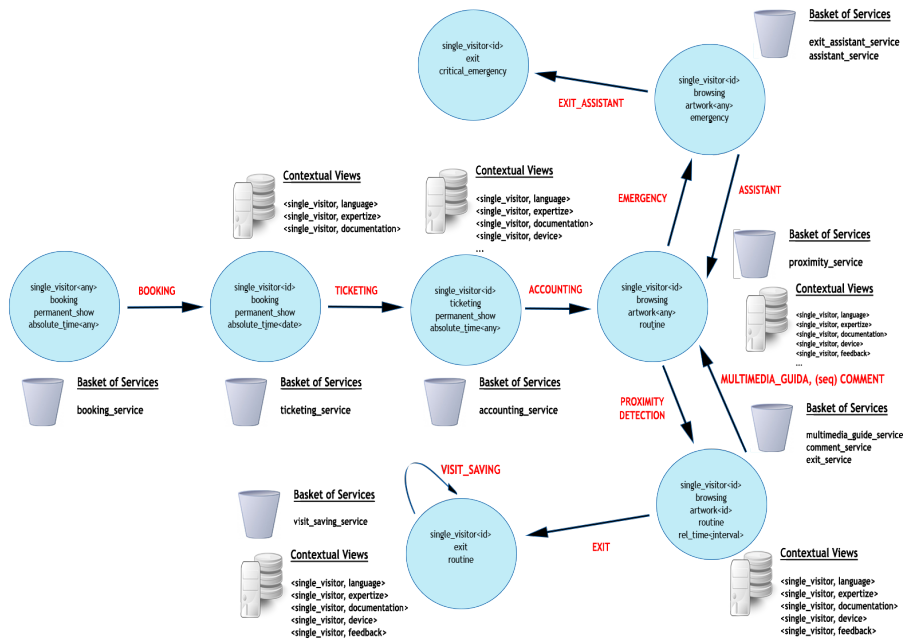


Figure 3: A part of CEG for a visitor user.

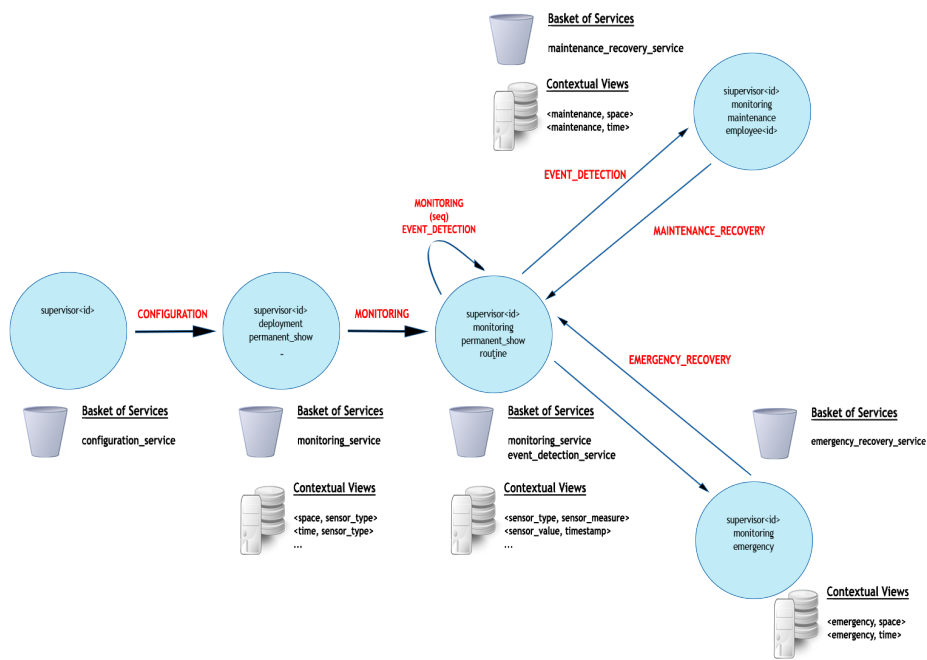


Figure 4: A part of CEG for a supervisor user.