Chapter 5
exhiSTORY: Smart Self-organizing Exhibits

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Abstract Creating stories for exhibitions is a fascinating and in parallel laborious task. As every exhibition is designed to tell a story, museum curators are responsible for identifying, for each exhibit, its aspects that fit to the message of the story and position the exhibit at the right place in the story thread. In this context, we analyze how the technological advances in the fields of sensors and Internet of Things can be utilized in order to construct a "smart space," which consists of self-organizing exhibits that cooperate with each other and provide visitors with comprehensible, rich, diverse, personalized, and highly stimulating experiences. We present the system named "exhiSTORY" that intends to provide the appropriate infrastructure to be used in museums and places where exhibitions are held in order to support smart exhibits. The architecture of the system and its application potential is presented and discussed.

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5.1 Introduction

An exhibition, which is usually formed by a number of exhibits, is not a simple set of objects randomly selected and placed altogether. In reality, an exhibition is designed to “narrate a story” [35]. The procedure of selecting exhibits and designing stories to be told by them is a tedious task that requires highly trained curators [24] as they are responsible for a large part of a museum’s budget [25]. These issues lead museums to utilize only a portion of the exhibits that they own [22], while the presented number of stories that the selected exhibits can narrate may also be limited.

Theoretically, the work of the curator is to organize exhibits within a limited amount of space in order to describe a story [20]. Practically, the analysis of objects and the extraction of a common story is a tedious procedure, as the curator needs to identify the links between the exhibits as well as the description of a definite and meaningful story. On the other hand, the visitors of a place need to be provided with information that reveal the “hidden” story of the exhibition, which is typically conveyed using multimedia information, e.g., text, audio, video, and images. However, even with application of all the aforementioned procedures, this way of exhibition setup is able to provide only a limited number of views to the visitors, and more specifically can stimulate only the visitors that are able to recognize at least one of the stories woven by the curator—and are also interested in at least one of them.

As a matter of fact, every single object of an exhibition has many different stories to tell, for example, Titian’s “Diana and Callisto” (Fig. 5.1) [12] can tell us about ancient Greek gods; about deception wrath and humiliation; nudity in art; about the artist’s personal style or the trends of the artistic period; and so forth. It is obvious that from a single piece of art it is possible to extract a number of different views; when more exhibits are combined then it is expected that the combination of stories is countless, for instance, when the painting of Diana and Callisto is next to The Arnolfini Portrait (Fig. 5.2 [36]) a new set of stories and connections can emerge, like wanted and unwanted pregnancies (both show pregnant women in different situations), maternity practices, etc. Similarly, if all three are connected, then new connections can be revealed like women’s rights, European art, social practices around female appearance, etc. Despite that, only few stories are selected to be presented in every exhibition.

This is the reason a number of projects such as PEACH [34], HyperAudio, and HIPS [30] combine the content of the museum and the context under which an exhibit is viewed in order to construct context-aware museum guides. In this manner, they are able to tell automatically synthesized stories utilizing narration generation algorithms. The generated stories can be further refined or filtered to match the user interests, the visitor model, the interaction history, or any other context parameter. These works are based on the fact that exhibits are static objects placed “forever” in a place combined with a set of similar objects. As such, when new exhibits are introduced, or if an object is removed or placed in other location, the whole procedure of narration generation must be reproduced in order to match the new setup. That being told, there is a strong need for manual work to be done which in most of the

Fig. 5.1 Titian's "Diana and Calisto"

Fig. 5.2 Jan Van Eyck's "The Arnolfini Portrait"

cases is laborious. Furthermore, the previous works imply that the curators should be able to record the metadata of each of the objects to be included to the automatic narration generation procedure; this means that they must have knowledge of deep semantic content, which in most of the case is trivial and usually does not include unexpected relationships between exhibits.

Going a step back we examine the research area of Internet of Things (IoT) which is flourishing the last years. The landscape of IoT is getting thoroughly analyzed, meaning that communication technologies, discovery functionalities, and mechanisms are studied in detail [6].

In [8, 9], the idea of the single smart space concept and its capabilities is defined. They actually represent a new way of realizing the concept of smart spaces within the cultural heritage domain. Similarly to what we present in our work, a form of "smart exhibit" is presented. A *server* smart exhibit may retrieve multimedia files from *client* exhibits, but apart from data exchange there is no description of self-organized exhibition or personalized narration based on the architecture of the IoT-based system. Indoor cultural activities have been also studied within the framework of the IoT and significant factors that affect the museum visits have been identified, like the visit context [17]. Another example of museum IoT system is the iPhone App, "Take me I'm yours." The project explores ways that objects can talk to the visitors and require actions [33].

Discussing about mobility, as visitors usually are "moving objects" into a smart space, we need to rely on this aspect when analyzing cultural heritage visits [41]. IoT research is coupled with mobile devices as a way to assist people in their everyday lives. Current research is focusing on unique ways to interact with appliances in the surrounding environment with the user's mobile devices [11]. One of the most known and award winning works regarding IoT, mobility, and cultural heritage was the QRator project applied at the UCL Grant museum of Zoology. Internet-linked interactive museum item labels were used to construct narratives and increase visitor engagement [21].

In this paper, we present the transformation of plain objects to *smart exhibits*. Smart exhibits are able to have "knowledge" of their own stories, communicate with each other, are able to self-organize as well as offer more than a simple presentation of themselves but also provide rich, diverse, and highly stimulating experience to the visitors. In that scope we develop exhiSTORY (from the Greek word $\epsilon\xi\iota\sigma\tau o\rho\epsilon\acute{\iota}$: tells a story), a framework that allows for self-aware exhibits positioned within the same smart space, to cooperate and work together, to produce self-organized exhibitions, each one telling a coherent story. Besides information that accompany exhibits in real, exhiSTORY also considers information regarding each individual user, such as interests, visit context, user device capabilities, etc., thus generating tailor-made museum visiting experiences, adjusted to each one's preferences, interests, and style, increasing the overall quality of experience. In this paper, we focus on a special infrastructure that allows exhibits to interconnect and interact with each other and with the visitors.

The rest of this paper is organized as follows: in Sect. 5.2, we discuss the stories that could be told by self-aware and information-rich exhibits, while in Sect. 5.3 we explore different methods for implementing smart exhibits in the context of IoT and discuss how self-organization of exhibitions can be accomplished in each option. Continuing, in Sect. 5.4 we present the architecture of exhiSTORY, the framework that generates the stories to be told and in Sect. 5.5 we describe the system in operation. Finally, we close our discussion in Sect. 5.6 with our concluding remarks.

5.2 The Stories Told by Exhibits

In a conventional museum, each exhibit is accompanied by an information label, usually presenting certain information such as the title, the name of the artist, and the time of creation, possibly complemented with a brief description.

Of course, via the process of duration, the museum holds a lot more information regarding any item, information that typically include the context of the creation, the context of the artist (who taught him, who inspired him), the context of the content (what is depicted, what the artist meant to convey, what other theories exist regarding its meaning or intentions) as well as the history of the exhibit as an item. Various museum information standards, including the Cataloguing Cultural Objects (CCO) standard [7] and the SPECTRUM standard [10] organize this additional information into concrete structures, and describe best practices for populating these structures.

Additional information cannot be presented in a typical setting as there is limited space for detailed information. However, by shifting the narration viewpoint from the whole of the exhibition space to the exhibit and allowing the exhibit to present itself exploiting its own plentiful information and taking into account the context of its surroundings, richer experiences could be offered to visitors. For example, regarding the presentation of its own information, it is now possible for the exhibit "Diana and Callisto" to present to us all the information that could not be displayed in its small accompanying label. However, the full potential of the exhiSTORY system stems from the fact that having access to the full context and semantic information of the exhibits opens up great opportunities, which could be focused on looking for connections between them. Google[1] has experimented with the notion of x degrees of separation of items in museum collections based on their visual similarity [23], but we find the **semantic** notion of x degrees of separation far more stimulating.

In this notion, we suggest that given any pair of items meaningful links between them can be located with a reasonably small number of steps that go through facts related not only to history or art, but also to popular culture and any available information about the target user's memories and interests; experiments reported in [40] provide evidence that user-specific intermediate entities can be used as elements of the path linking two nodes in a semantic network, and we plan to further explore this issue through experiments specifically targeted to the aforementioned aspects (popular culture, user's memories, and interests).

The aforementioned incline to an innovative assumption. The main idea is that every object that is considered to be part of our heritage has knowledge about itself and a character; the knowledge and character is not confined to the standard information that accompany an object (this typically includes the creator—artist—the creation date, the material, and the usage), but also encompasses a whole new set of data that could include information like: what do I mean, with which concepts am I related and under which interpretation, where have I traveled, how many people have seen me, how many generations know me, or what are other objects that we co-existed at the same place. In this manner, large parts of hidden histories will be revealed. In

[1] Google Inc. http://google.com.

parallel, the interconnection of each object and the person observing it can be further analyzed, thus allowing experience personalization. Exploitation of the profile can be achieved through social networks, web platforms, or alternate procedures [1, 13, 16, 18].

It is inevitable that advances in technology affected the procedure through which a narration is recognized and presented to visitors. The "PEACH" project uses mobile devices and uses cinematic techniques in order to create a feeling of personalized TV. The documentary-like content also adapted to the interests of the user [32]. Another known system is "HIPS" (Hyper-Interaction within Physical Space), a hypermedia system supporting mobile presentation of museum and historical information. Tourists' positions were detected and auditory information was personalized and context depended [5]. The main principle of the application was that information is context dependent, and thus it should be presented in different ways [30]. The environment became an interface and the visitor's movements became a form of input to the system. HIPS assumed that different visiting styles need different durations for the presentations and the empirical data support this hypothesis [15]. HIPS was using infrared emitters to connect to the users devices (PDAs) [27]. Finally, user testing and evaluation showed that all users liked the idea of receiving information related to their movement. In addition, in the experimental cases where the visiting style was matched to appropriate content, the users demonstrated increased interest by requesting more information about the exhibits explicitly [27].

The *exhiSTORY* system complements the aforementioned approaches to multiple narrative generation and personalization by exploiting IoT technologies, through which exhibits are able to contribute their own semantic information to the venue, coordinate and collaborate to tell a coherent story to a visitor according to her profile. In addition, exhiSTORY provides the relevant infrastructure to materialize this combination.

In this paper, we propose an ad hoc network that includes objects and people. This network will be able to interact uniquely with each person according to parameters that may include among others the enriched content history of an object. The ultimate goal is to calculate the degrees of separation between objects and people, targeting to the maximization of the impact that can exist through the interactions of people and cultural heritage objects; the approach presented in [3] is one possible way to do this.

In the next section, we explore different approaches for implementing smart, self-aware exhibits in the context of IoT and discuss how self-organization of exhibitions can be accomplished in each option.

5.3 The Smart Exhibit

Analyzing the information discussed in Sect. 5.2 we realize that, in order to achieve an automated procedure for creating stories from sets of objects, each object must carry information such as origins, history, meaning, interpretations, and context.

Fig. 5.3 The smart exhibit

Moreover, there is a strong need for sharing of this information as well as enriching and updating this information either manually or automatically (Fig. 5.3). Different implementation approaches are reviewed below in an attempt to identify the desired characteristics for exhiSTORY's infrastructure. In the following, we review the main options available and examine the strengths and weaknesses of each approach concluding to solutions that can be applied to different types of venues in order to have optimal use.

Elementary implementation. Exhibits carry an RFID tag providing only a single identification number. The RFID tag is sensed by RFID readers hosted in the exhibition rooms, which notify a museum-hosted server regarding the locations of the exhibits [38]. The museum-hosted server maintains a repository containing all the information (descriptions, semantic information, and RFID identifications) for the exhibits that it accommodates, therefore having obtained the exhibit location information from the RFID readers, it can run logic for exhibit presentation and dynamic exhibition formulation. Visitors receive the exhibition and exhibit information by connecting to the server through standard Internet connectivity, typically supported through Wi-Fi access points installed by the museum. Visitor requests to the server may contain visitor profile information, which the server can exploit to perform personalization (Fig. 5.4).

The core benefit of this implementation is its low cost, as only RFID tags and readers are needed. An RFID sensing grid must also be installed in the venue to support automated geolocation of exhibits. More details on the process of automatically geolocating exhibits using RFID tags are provided in Sect. 5.3.2.

On the other hand, the exhibits with this approach do not truly "carry" their information: that information is stored on a museum-hosted server, limiting the scope of the approach to exhibit mobility within a single museum. If an exhibit is moved from one museum to another, the exhibit-related information must be manually entered or imported to the server of the receiving museum.

Security in this implementation option is high, as a malicious visitor can only emulate one of the RFID tags of the exhibition, trying to trick the system to believe that an exhibit is at a place other than its true location (as contrasted to subsequent approaches where malicious parties can try to inject content to the exhibition).

Fig. 5.4 Elementary implementation

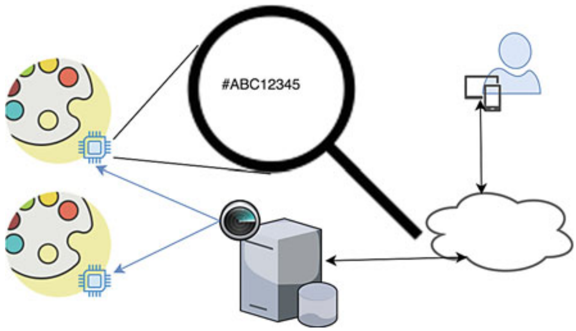
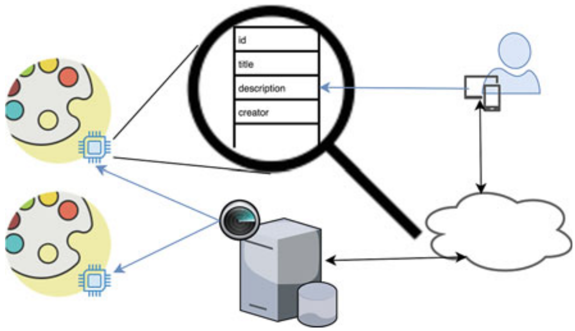


Fig. 5.5 Basic implementation



A discussion on the security aspects of the different smart exhibit implementations is provided in Sect. 5.3.3.

Basic implementation. Same as the elementary implementation, but the RFID chip also has the exhibits' basic information, such as title and creator, as well as a brief description including key semantic properties. Typically, an RFID tag can accommodate up to 2 KB of data [31], so the amount of this information is essentially limited and external storage services are required to store additional data for the exhibit, including extended semantic data, multimedia files, enhanced descriptions, histories, and so forth. These storage services will be provided by the museum's server (Fig. 5.5).

Similar to the elementary implementation, the museum-hosted server undertakes the exhibit presentation and dynamic exhibition formulation, as well as the delivery of information to visitors. However, in this option each exhibit "carries" along some information when it is moved from one museum to another, hence the receiving museum server can retrieve this information in a plug-and-play fashion and use it to readily integrate the exhibit to the museum's collections (or even formulate new collections). Typically though, additional information (such as multimedia files and extended descriptions) will need to be entered or imported to the museum server for the exhibit, in order to enable presentation of rich information and enhanced storytelling features.

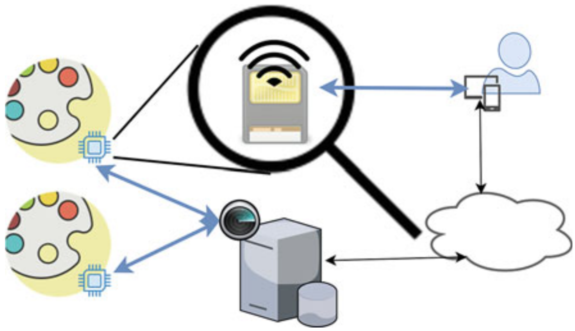


Fig. 5.6 Memory-rich implementation

Exhibit geolocation in this case is performed in the same manner as with the elementary implementation and is discussed in Sect. 5.3.2. Regarding security, the risk in this case is higher than the case of elementary implementation, since exhibits carry information and a malicious party can exploit this feature to inject content into the exhibition; a relevant discussion is presented in Sect. 5.3.3.

Both elementary and base implementations are similar to the condition under which is currently the exhibits in the museums with the differentiation of having a mechanism on them has a number of data stored within. No communication can be achieved other than a device scanning the mechanism (RFID in our occasion) in order to obtain this information. This concludes to the fact that the first can even be achieved with some form of ID presentation such as a barcode or a 3D code (e.g., QR code).

Memory-rich implementation. By enhancing exhibits with memory-rich capabilities, there is the option of data exchange and communication, which is a major differentiation with respect to the already presented solutions. Supposing that each exhibit can have large storage so as to "carry" its own information, then what is required is a means of communication. This can be implemented by having *FlashAir* cards [39] installed on them, which may provide from 8 to 32 GB of storage space, plus wireless LAN communication capabilities. These imply that the existing information and any derived or computed information can possibly be stored within the exhibit (Fig. 5.6).

The implementation scheme allows mobility and automation during the procedures of exhibition organization in any place, any time. As the exhibits provide with content the system requires a server that is able to discover exhibits aligned together and perform all the processes that lead to exhibition formulation and presentation of personalized information. The museum-hosted server may store additional data on the exhibit's memory, such as the exhibitions it has participated in or information regarding the profile of the visitors that have viewed it, thus the exhibit's level of self-awareness can be progressively elevated. Exhibit geolocation can be fostered by standardized Wi-Fi triangulation or Wi-Fi fingerprinting methods [4, 28]; alternatively RFID tags can be also attached to exhibits to implement geolocation through an RFID reader antenna grid. Exhibit geolocation is further discussed in Sect. 5.3.2.

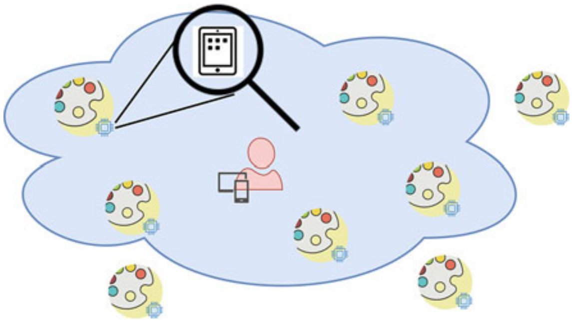


Fig. 5.7 Agent implementation

The cost in this case is higher. The main disadvantage to be considered is that exhibits will now require to be connected to a source of power to sustain the operation of the *FlashAir* cards. Security is also an issue to consider, as (1) exhibit storage is writable and (2) visitors are presented with information and media files provided by the exhibits, so a malicious party may try to emulate an exhibit, and thus inject content into the exhibitions. Security risks and mitigation options are discussed in Sect. 5.3.3.

Agent implementation. This implementation includes a small device (e.g., a low-cost embedded device) that accompanies each exhibit. In this occasion, each exhibit acts as an intelligent software agent. Consequently, there is no need for a centralized server as the whole procedure is based on ad hoc networks created by intelligent agents with enough computational power as well as connectivity in order to achieve the system's desired procedures. The levels of independence of each exhibit are such that the system is not limited to indoor settings. Personalization is possible if visitors are able to become peers of the ad hoc exhibition network and share personalization information (Fig. 5.7).

Exhibits can be automatically geolocated, by exploiting their Wi-Fi signal strength, using standardized Wi-Fi triangulation or Wi-Fi fingerprinting methods [4, 28] (c.f. Sect. 5.3.2). Furthermore, GPS units for low-cost embedded devices do not affect much the cost of the overall system. As is often the case with agent-based systems, security risks are highest as a malicious user can join the network of exhibits and participate as a peer in the negotiation and decision-making process, co-shaping the content to be displayed on all exhibits. These security risks can be addressed through the use of public key cryptography, as discussed in Sect. 5.3.3.

5.3.1 Centralized System Control

The implementations presented are intended to provide information about how the environment can be formed and understood; the choice among the implementations is directly related to the exhibits and the exhibitions as well as the capabilities and particularities of each venue. In most of the cases, a local server is responsible for exchanging information with the exhibits. The approach of a local server used to perform all the procedures offers simplicity in terms of technology and algorithms, despite the fact that it may require ample computational power and storage space to accommodate the needs of the exhibits; depending on the storage capabilities of the exhibits and the information stored on them the role of the server is differentiated, as its main role apart of the facilitation of the exchange of information is to store what cannot be stored on the exhibits. Scalability for this system can be provided by exploiting the elasticity feature of standard cloud architectures.

In this work, we will further elaborate on an architecture based on the memory-rich implementation of smart exhibits. The rationale behind choosing the memory-rich implementation of smart exhibits as a demonstrator was based on the following aspects:

- in this implementation exhibits carry with them all their information, making them self-contained objects that are seamlessly integrated into the IoT architecture;
- this implementation uses standard, "off-the-shelf" components (*FlashAir* cards), with an affordable cost, as contrasted with the *agent* implementation, where either custom hardware needs to be built or a small computer, with higher cost than *FlashAir* cards, needs to be used.

According to the aforementioned, we should be able to create a more generic architecture that could support all the implementations described, at least the ones that require less technical setup than the one selected. Of course, we should always pay attention on the capabilities and constraints of the place to be supported by the system as defined in Sect. 5.3.4.

5.3.2 Automated Exhibit Geolocation

An important aspect of a sensors system applied on a set of moving objects is based on the definition of the geolocation. Automated exhibit geolocation can be performed by exploiting the RFID tags attached to the exhibits and/or the Wi-Fi adapters which exhibits carry, depending on the smart exhibit implementation adopted by the venue. In the case of the museums, we need a very precise geolocation of each object in order to achieve the best narrative for the visitors. According to [38], RFID tags can be used to geolocate objects, exploiting the signal strength captured by appropriately placed RFID reader antennas. This work asserts that the detection of passive RFID tags provides excellent precision when the distance between the reader antenna and the tag is up to 3 m, and exceeds 75 % for distances up to 4.5 m, hence setting up a 2 m × 2 m rectangular grid of reader antennas will provide adequate precision for geolocating the exhibits. The number of required reader antennas can be, however, significantly reduced by exploiting the fact that when venue exhibitions are restructured, a number of exhibits within the exhibitions are not moved. Therefore, exhibits that remain still can be used as reference tags, and by applying a weighted-center of gravity technique, one reader antenna can be proved sufficient for an area of 12 m by 10 m, providing a level of accuracy of about 1.07 m [19]. This setup is adequate for the positioning the exhibits within the generated narratives (the visitor can be directed to elements of the narrative at exhibition room level or exhibition room area level). These approaches apply to the elementary and the basic implementation for smart exhibits. Note that instead of polling for non-moved exhibits to identify reference tags, extra RFID tags can be positioned in the venue to play this role, i.e., provide reference points for geolocating exhibits.

When smart exhibits are implemented using either the memory-rich or the agent approach, the Wi-Fi adapters carried by the exhibits can be exploited to provide exhibit geolocation. In this case, the museum needs to have available a set of Wi-Fi access points, and then techniques such as Wi-Fi fingerprinting or trilateration [28] can be used to perform exhibit geolocation. Wi-Fi geolocation methods have been successfully used for identifying visitor locations in the Experimedia Blue project [26, 29], while the Art Institute of Chicago (AIC) has also used Wi-Fi-based geolocation to compute the location of visitors reliably within a range of 10 m [37]. If exhibits also carry an RFID tag, RFID readers can be used as an additional source of geolocation information as described above. In case of more than one sources of geolocation information, the more precise is selected to be used.

5.3.3 Security Aspects

Security is a base aspect of every system that includes communication and connection to end users. The complexity of the system negatively correlates with its security, meaning that the simpler the system, the higher the security. In case of elementary and basic implementations, the exhibits either carry only their identification, or their identification along with some limited information about them. As such, the only security issue that can occur is the user emulating the RFID tag, thus tricking the system in believing that the exhibit is placed at a different location than the real one. However, the problem can be detected by examining the uniqueness of each RFID transmitted. As mentioned in Sect. 5.3 in the cases of system setup with dynamic two-way information exchange, there is a possibility of malicious users trying to emulate an exhibit. What one can achieve by emulating an exhibit could be from simply inserting content into the system procedure, to trying to acquire user profiling information. In the case of the *FlashAir* cards, a first precaution measure is to utilize the security features existing within the hardware and the accompanying software in order to prevent emulation or data acquiring or alteration. The basic feature that can be utilized is the configuration of the devices to Wireless LAN client mode [14] and force their setup for network connection to point to a specific device. In parallel, the connection point (Access point) that objects are connected to has to be configured to allow connection only to devices with specific characteristics which will be connected as exhibit content providers. In this way, we are assured that no malicious device can be connected to this network and exchange any kind of information but on the other hand every exhibit added to the collection needs to be carefully setup by a technical expert.

5.3.4 Selecting an Implementation Option for Smart Exhibits

Above, four different implementation options for smart exhibits have been described. In this subsection, we provide some guidelines regarding the selection among the different implementation options. *The cost factor*: Cost is probably the most important factor to consider, since if some implementation option is beyond the budget capabilities of the venue, then it is clearly inapplicable and cannot be considered further. Regarding the cost criterion, the two RFID-based techniques (elementary and basic implementation) have an edge, since the cost of the RFID tags is minimal. Building a dense array of RFID reader antennas can prove costly, especially for large spaces, however exploiting stationary exhibits or reference RFID tags to assist in geolocating other exhibits can significantly reduce the cost. The memory-rich implementation is ranked next, with a final cost of the complete setup described ranging from \$35 to 37. Finally, the agent-based implementation is the most costly one: the most straightforward way to realize this solution is to use a low-cost, capable of performing the desired procedures, smartphone starting from approximately \$60.

Installation and cabling: Installation and cabling could be a very challenging task, since most venues follow strict policies regarding physical interventions in their premises. Despite the fact that RFID installations seems the easiest approach, since it does not require many physical changes of the exhibition space, nevertheless it requires many changes to the building, since it demands the use of RFID antenna grids. On the other hand, the use of complex installation equipment for the exhibits (memory-rich and agent-based) does not require any change to the actual venue building but a large device must accompany each exhibit, since individual power sources are needed, leading to extensive cabling in the exhibition space.

Compatibility with existing software: When dealing with software installed in museums we need to take under consideration the fact that existing narrative generation systems for museums (e.g., [5, 30]) assume that a central database holding the exhibit information exists. The software to be installed and used for the implementation of exhiSTORY system is related to the actual system architecture selected. In case of elementary implementation, the existing infrastructure of a museum could be sufficient for making the system work. In every other occasion, though, there is strong need for installation of extra software as a centralized database needs to be used. Furthermore, the infrastructure has to be in-line with the security implementation which may require software changes to the server so as to be able to recognize the objects' certificates. Finally, the agent-based approach requires advanced software installed on objects' end devices that will manage the interaction between them and the users.

Security: While all implementation options can provide high levels of security, as described in Sect. 5.3.3, the two RFID-based solutions require only minimal knowledge and expertise from the museum staff, while the other two options necessitate appropriate expertise from the museum staff (configuration of wireless LANs and knowledge on public key cryptography), which has to be done once though.

Final selection: According to the discussion and analysis on the different approaches, it seems that if a museum is able to address the cost and in-place changes, the most preferable implementations is either memory-rich or agent-based, as they are much more advanced than the RFID solutions. Furthermore, comparing the final two candidates we are leading to the result according to the capability of utilizing existing software versus building an autonomous agent system. Despite that the second option is more flexible and advanced, if there is the option of utilizing already existing systems, the memory-rich implementation should be preferable.

5.4 System Architecture

The main purpose of the described system is to enhance the experience that a visitor can acquire in an exhibition place. This is achieved by altering the exhibits and the place setup in order to comply with every aspect of the system described. The architecture that is described in Sect. 5.8 is essential in order to give life to the set of smart exhibits. It includes the "smart space," the knowledge base and a set of intelligent modules.

5.4.1 The Smart Space

Mobility of the exhibits is a core concept in exhiSTORY, meaning that the smart space is a dynamically defined area that is able to identify changes in location, movements, additions, or subtractions of objects. In the cases of solutions with RFID, the smart space includes a dense grid of readers, while in other solutions a network of Wi-Fi access points is required to support the space. The precision of estimating the location should not be very high. It is required though to have a rough estimate of the position. Moreover, what is actually required is to be able to have the knowledge of the proximity between objects and information of the order of object viewing, as discussed in detail in Sect. 5.3.2. The Wi-Fi network is required in every solution as it is the medium through which the system is able to communicate with the visitors, so it should be such that can cover every space, or at least the spaces that are very close to the exhibits.

5.4.2 The Knowledge Base

As already mentioned in the description of the exhiSTORY system, we should be able to have deep knowledge of the data that accompany the objects, as well as information about the visitors (user profile) in order to be able to provide an advanced user experience. In this manner, the knowledge base of the system includes the following:

- *The museum's context*. The context consists of information about the style of every exhibition, including style, related and incongruous topics, and ways of presentation.
- *The museum semantics*. Semantics is curated information that is related to each institute's interest. This kind of information is by far more reliable than knowledge acquired from any other sources—Internet or information within the smart exhibits.
- *The museum media*. Multimedia that is available to the museum and can be used in the presentation of stories and can or cannot be used under the current institute setup.
- *Museum map information*. This information includes a map of the layout accompanied with metadata comprising the Wi-Fi Access Point or/and RFID reader positioning.

The aforementioned knowledge base items exist when the system is set up and is ready to be launched. These data are completed with information acquired during system execution and are related to the user profiling data.

These form the actual database of the system and should be present in any system installation in order to be able to create links between the vast amount of data. The connection between information that leads to the creation of stories for the maximization of the visitors' experience is done by the intelligent components.

5.4.3 The Intelligent Modules

Detailed definition of the intelligent modules remains out of scope of this paper as our main intention is to describe the system architecture that leads to exhiSTORY forming smart exhibitions. As illustrated from Fig. 5.8 that presents the system architecture, the intelligent modules include: the exhibit tracker, the semantics engine, the story finder and maker, the media engine, and the user profiling. They are all defined as part of the main component of the service that is executed within the scope of the exhiSTORY system as they are highly interconnected. The core software of the system is beyond the scope of this manuscript which focuses on the construction of the sensors' architecture.

The *exhibit tracker* is the simplest of the modules. By using either the grid of RFID sensors, the position of the Wi-Fi access points or the geolocation unit of the object it is able to estimate the exact location of the exhibit. *Media engine* is responsible for enriching the systems' outcomes with multimedia such as text, video, audio, images, animation, or 3D objects. By locating the semantic interconnection of the objects to the system generated story metadata it is able to provide relevant media to be selected for each generated story.

The semantics engine is in charge of collecting information about the exhibits and the topics that are related to them. Firstly, an amount of semantic information is directly related to the smart exhibit and more precisely the exhibits' "memory." Furthermore, additional information can be gathered directly from the knowledge base and from reliable online sources such as cultural or historical Wikis and encyclopedias.

Relying on the "x degrees of semantic separation" the *story finder and maker* analyzes the context of each exhibit and tries to locate bonds between the objects within the semantics. Detailed description of the procedure of this system is presented in [3]. It is important to note that the system is in search of non-trivial connections between the objects as it is expected that the museums' curators should be able to identify the obvious and trite. After locating the interconnection between the objects, the part of this module that is responsible for creating the stories formulates the scenario. The scenario is based on the place of the exhibit the sequence of objects that a visitor will see and the content that is related to the semantics.

Finally, the system is furthermore enhanced with the user profiling module which is responsible for collecting implicit and explicit information about user profiles whenever possible. By doing this the system is able to apply personalization techniques to the creation of stories tailor-made to the profile of each user.

After available stories have been ranked, the ones attaining the highest scores are suggested to the user to choose from.

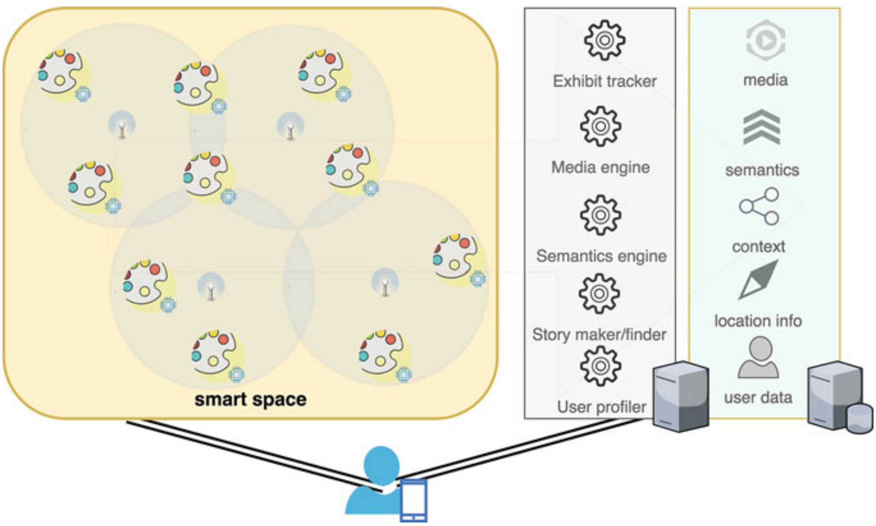


Fig. 5.8 The exhiSTORY architecture

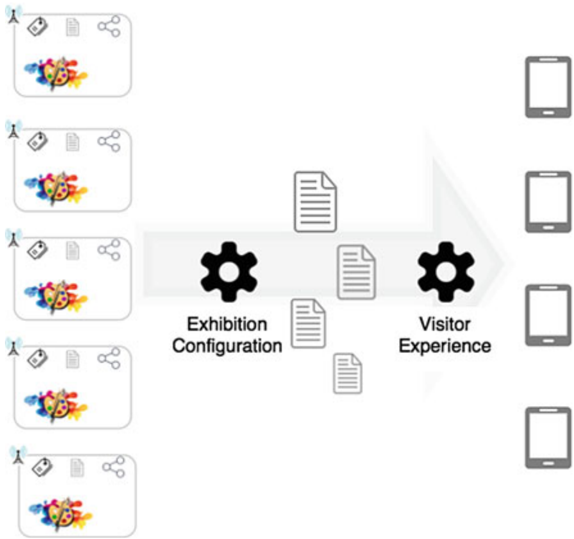


Fig. 5.9 The exhiSTORY system in operation

5.5 The exhiSTORY System in Operation

The operation of the exhiSTORY system (Fig. 5.9) is separated into two processes: the exhibition configuration and the visitor experience mode. Although the two processes are distinct, and can be associated to the offline and online modes of operation of most conventional systems, it is worth noting that they may be concurrent, as in exhiSTORY reconfiguration can take place at any moment.

The exhibition configuration process involves the geolocation sensors of the smart space, the exhibit tracker, the semantics and media engines, and the story finder and the story maker. It is the process that takes as input the list of smart exhibits and generates the detailed scenarios of the stories; its operation has been explained in Sect. 5.4.

The delivery of the visitor experience involves the Wi-Fi network, the user profiling module, and the story selector procedure. Additionally, since the memory-rich smart exhibits do not have incorporated display facilities, a mobile device is also necessary. A custom device could be created, but that is not a necessity as visitors' own mobile devices, such as smart phones and tablets, can be used, provided that the exhiSTORY application has been installed in them and is running.

The application can be downloaded and installed prior to the visit to the museum. Upon loading, the application prompts the user to connect via a Facebook account and/or to play some online games that are related to culture. While these steps are optional, they allow the system to compile an initial profile for the user, by sourcing relevant data from the user's Facebook profile or analyzing the user's behavior within the games to deduce personality traits of the user, such as MBTI dimensions (extraversion versus introversion, thinking versus feeling), etc. [2]. These profile data will then be exploited in the context of the personalization process. Additional sources of user profiling information, such as social network profiles [13] or web platform profiles [16], can be used.

When inside the museum, the application connects to the exhiSTORY system, transmitting to it user profile data and visitor history information, which is used by the story selector procedure to provide an ordered list the most prominent stories. When the user selects a story, the narration (and navigation) commences. Any mobile device equipped with a graphic screen, Wi-Fi connectivity and having the ability to execute custom applications network, such as a smartphone or a tablet, can be used as a user access device.

5.6 Discussion and Conclusions

It is inevitable that in the current state of museums the procedure of changing an exhibition by moving, altering, removing, or adding exhibits is a laborious one. Curators need to invest time and effort to set up a new exhibition, although the information presented is only a fraction of the available information for each exhibit. These all lead to the conclusion that it is very difficult to create media-rich exhibitions with an increased quality of experience for each visitor without the use of relevant technology. In this manner, we presented the exhiSTORY system, which allows smart exhibits to be automatically and dynamically organized into exhibitions. The exhiSTORY system delivers the narration of the exhibition through individual visitor devices, and considers user style, preferences, background, history, and so forth to present visitors with tailor-made experiences.

The exhiSTORY framework has been designed in part in the context of the Cross-Cult EU project, and will have its trial application in the implementation of one of the projects' pilots. That pilot will run at the Archaeological Museum of Tripolis in Greece, where we have found at least 7 different stories can be told by approximately 30 exhibits, depending on the configuration of the visit and the presentation. It will be fascinating to observe as the exhibition reconfigures itself when exhibits are added, removed, or simply rearranged in the museum's rooms. It will also be interesting to see how the exhibition evolves from day to day, based on social media trending topics, or how visitors in the same group are served with different contents. But, in all fairness, this trial will neither test nor demonstrate the full potential of the smart exhibit notion.

The concept of the exhiSTORY system is the "smart place" that includes smart self-organized autonomous objects. In this notion, we are creating a new research path with a large amount of challenges to be faced. We analyzed a number of alternatives that can be used in the technical part and described the solutions for each of the cases in order to produce a complete system, according to each museum's peculiarities. In these cases, we need to examine the interconnection of data in different museums as well as the cost analysis of the seamless and agent-driven implementations that seem to have large cost especially for museums with large numbers of objects. Solutions including novel sensors could be also investigated as well as custom devices based on electronic prototyping platforms like Arduino,[2] BeagleBone,[3] or Raspberry Pi.[4]

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