A Smart Space-Based Design of Semantic Layer for Advancing Museum Information Services

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***Abstract*—Nowadays many museums are being transformed to some "smart" variants: a cultural space in a digitally-equipped environment is formed where cultural heritage knowledge can be easily and collaboratively usable and creatable by interested visitors as well as by professionals. By using such innovative technologies as Internet of Things (IoT) and Smart Spaces it is possible to shorten the distance between museum exhibits and collected historical information on one side and consumers and providers of this information on the other side. In this paper, we study the smart museum concept for development of software that realizes connection between the involved actors and shared cultural heritage knowledge. Our research and development are focused on designing a semantic layer in the form of a software infrastructure. This infrastructure is a middleware on top of which such advanced museum information services can be constructed as personal visit planning, virtual exhibition preparation, and collaborative enrichment the museum collection. We introduce a suit of smart space-based solutions to create this type of software infrastructures. The generic solutions are theoretically analyzed based on the case study of the History Museum of Petrozavodsk State University (PetrSU).**

I. INTRODUCTION

Museums play an important role in promoting cultural heritage knowledge [1]. A traditional museum has a database or a museum information system (MIS), which serves as an electronic archive or catalogue [2], [3]. As a rule, such a MIS is used only by museum personnel. Visitors cannot access the MIS are the access functions are very limited (browsing some collected information). Internet of Things [4] are drastically changing this traditional way of visitor leaning in a museum. Exhibits are transformed to IoT objects providing information about themselves or even interacting with users and other objects, as it happens in IoT in general case [5], [6].

The IoT technology enables an integration of MIS with visitors' activities, opening a wide range of possibilities to engage the museum visitors with exhibits and all available information about them. In this paper, we study the smart museum concept for development of software infrastructure that realizes connection between the involved actors and shared cultural heritage knowledge in a museum. To develop the software infrastructure we design a suite of solutions that implements a semantic layer. The latter operates uniformly with physical exhibits (traditional cultural heritage representation) and information exhibits (e.g., photos or audio interview records). The role of this semantic layer is to make fusion of the physical surrounding and information worlds in the common digital environment. Based on this fusion the museum becomes not just a collection of cultural heritage information with passive consumption. Instead, the museum becomes a collaborative work environment where cultural heritage knowledge can be easily and collaboratively usable and creatable by interested visitors as well as by professionals.

A general approach to development this kind of advanced service-oriented environments is smart spaces, see [7], [8]. A smart space defines a computing environment where heterogeneous digital devices share their computational and informational resources. Smart space can provide such devices with context-dependent information, communication, services, and personalized recommendations using integration of the agent and data mining technologies [9]. In the studied smart museum case, the smart space involves many informational objects. For their integration we introduce the semantic layer. The latter can be thought as a semantic network where all participating objects are virtually represented and interconnected, similarly as it happens in Semantic Web [10], [11], [12]. The semantic layer enhances the basic MIS to support construction and delivery of information services with high intelligence level. Services are able to take into account additional historical sources to enrich the museum exhibit descriptions collection. The sources are from MIS, from exhibits themselves as well as from museum visitors and personnel.

The smart space-based architecture is multi-agent [9]. Agents run on local digital equipment of the museum (e.g., multimedia devices), remote server machines (e.g., MIS server), and personal mobile devices (e.g., smartphones). The agents cooperatively construct a semantic network based on information and its semantic relations acquired from available sources. The agents operate with a common ontology for representing and linking the objects and other information in the semantic network. Construction of an information service is reduced to search and analysis in this semantic network. Delivery of an information service and possible participation in the service construction are based on the use of personal mobile devices, which become primary access and control points for the users.

The contribution of this paper is smart space-based design of the semantic layer. The proposed suit of solutions defines a software infrastructure—a middleware on top of which advanced museum information services can be constructed and delivered. We elaborate the design for such services as personal visit planning, virtual exhibition preparation, and collaborative enrichment the museum collection. The generic solutions are theoretically analyzed in respect to the case study of the History Museum of Petrozavodsk State University (PetrSU). The proposed solutions can serve as reference ones for development of other museum services as well as for other museums and cultural heritage areas.

The rest of the paper is organized as follows. Section II overviews existing approaches to development of information systems for museums. Section III describes the smart museum concept and the role of semantic layer. Section IV presents the smart space-based design of semantic layer, which allows implementing the software infrastructure. Section V introduces the ontology for the semantic network. Finally, Section VI concludes the paper.

II. Related work

Much attention is paid now to development of museum systems where operation with exhibits and related information is made easier and more effective. The traditional way is to create a database or museum information system (MIS). The latter keeps descriptions of the collected museum exhibits. For example, the online collection of the British Museum is a database that represents more than 3,5 million objects with associated records and images [13].

A lot of research and development work is made to enhance basic MIS functions, aiming at making a smart museum with so-called "smart services". One example of a smart museum is SMARTMUSEUM system [14]. The main function is recommendations on the route construction for exposition view based on information on the location and the visitor interest.

In [15], the authors presented a mobile guide for the visitors in an Italian museum. Wolfsoniana Smart Museum mobile application intended for research about usability and user experience of Near Field Communication (NFC) technology. The mobile application will interact with NFC and QR Code technologies to allow the visitor to easily access to additional contents and social functions with his/her smartphone.

For the semantic linkage of exhibit with other exhibit and entity (persons, events, historical facts as such, etc.), it is necessary to generate a historical knowledge base, i.e., semantically interconnected information about diverse objects. Currently, all public knowledge bases are represented in LOD Cloud by means of the Semantic Web technologies RDF or OWL. Ontology CIDOC CRM [16] is specially designed for the description of museum artifacts. Also, there have been made others attempts to present information of museums using ontologies.

Europeana project [17] aims at a single access point to numerous cultural heritage that have been digitized throughout Europe. Dataset of Europeana contains open metadata on approximately 2.4 million texts, images, videos and sounds gathered by Europeana. The Europeana Data Model is followed by metadata to including museum objects and archival records. Access to the Europeana is possible via executing SPARQL queries against the data set. Similarly, the British Museum online collection have SPARQL endpoint access.

Hajmoosaei *et al.* [18] considered the problem of semantic heterogeneity among museum data sources. Museum information system use multiple data sources to store the specifications of heritage entities. The proposed methodology of ontology development is an effective solution for representation the heritage information relating to museum exhibits.

Smirnov *et al.* [19] proposed the approach to context-oriented knowledge management for supporting visitors through their mobile device in museum smart environment. Museums are considered as a smart environment where each exhibit, group of exhibits, or museum is represented by a service or a set of services. The proposed approach allows assisting visitors (using their mobile devices), in planning their museum attending time and excursion plans depending on the context information about the current situation in the museum and visitors preferences.

III. Semantic layer

Many museums are created within such educational and research organizations as universities. As a typical representative of this class of museums we considered the History Museum of Petrozavodsk State University (PetrSU). This museum plays an important role in promoting cultural and historical information related to everyday life history around PetrSU and its activities. The museum is oriented to everyday life history. The exposition room is small while equipped with multi-media devices for effective learning and collaborative work, see Fig. 1

Many exhibits are presented as photographs and various textual documents, newspapers, academic journals, etc. A large part of museum photos are also stored in digital format. A special feature of the museum is the presence of virtual exposition presented on eight touch-screen screens (displays). The PetrSU MIS used to record exhibits and search for individual objects based on keywords in the formal fields. The large size of museum collection requires a more effective way for selecting and presenting the information in the exhibition room. For example, to form an exposition, detection of interrelated exhibits among available in the museum collection is needed.

The IoT and Smart Spaces technologies enable development of semantic information services operating with descriptions of museum exhibits and available historical information [20]. Development semantic information services solves problems adding semantic information and search exhibits, which are connected to each other even indirectly. The main purpose of semantic information services is collective semantic annotation, information linking, personalized access to corpus of museum exposition sources. The use of additional sources of information provides semantic enrichment of the museum collection. Personnel and visitors of the museum, as well as external Internet sources, are additional sources to collect and store information about museum exhibits. Users can add descriptions, new facts, and links to historical facts and other exhibits by semantic information services, enriching the museum collection with additional semantic information about everyday life history. Creating this kind of semantic information services will allow a quick search of exhibits and analysis of information about them to detect objects of interest to view.

For this purpose we introduce a semantic layer in a smart museum. The layer becomes responsible for construction and delivery of semantic information services. Consequently, such a smart museum becomes a cultural space where its semantic layer makes cultural heritage knowledge used and created by visitors and personnel. The semantic layer aims at solving the following application problems.

Fig. 1. Exposition room of the History Museum of PetrSU, the photo is from https://petrsu.ru/structure/585/muzejistoriipetrgu

Firstly, adding text and voice semantic annotation about the exhibits by the visitors and museum's personnel collectively. Adding annotations can be used for further research on everyday life history. As a result, the knowledge base on everyday life history is extended.

Secondly, semantic information linking of annotations about the exhibits in the museum collection, which leads to the emergence of many semantic relationships between the sources of the museum exposition. The result is a semantic network, which is formed based on museum knowledge corpus of existing annotated sources. The obtained semantic network can be analyzed by known mathematical methods, such as search and ranking [21].

Thirdly, personalized search for information about the exhibits based on explicit and implicit user requests taking into account the context. The search is based on semantic network. The found objects are ranked and can be further used to construct recommendations to the user.

Finally, automatic generation of a virtual exposition based to the visitor profiles and other personalized context information. In particular, such a virtual exposition in the History Museum of PetrSU can be represented by several screens, which show information about the exhibits in digital form and interactively.

The semantic layer structure of a smart museum is shown in the center of Fig. 2. In particular, the History Museum of PetrSU has eight touch screens: scr-1, . . . , scr-8. The semantic layer operates in a shared information space, which implements a knowledge base using the Semantic Web technologies. Shared information follows an ontology and is represented using Resource Description Framework (RDF). The information is stored in an RDF triplestore, which supports information search and processing extensions.

We consider the following particular semantic services: semantic enrichment service, visit service, and exhibition service. All of them are based on operation with the semantic network. The semantic network is a directed graph consisting of nodes (vertices), which represent domain objects, and edges, which

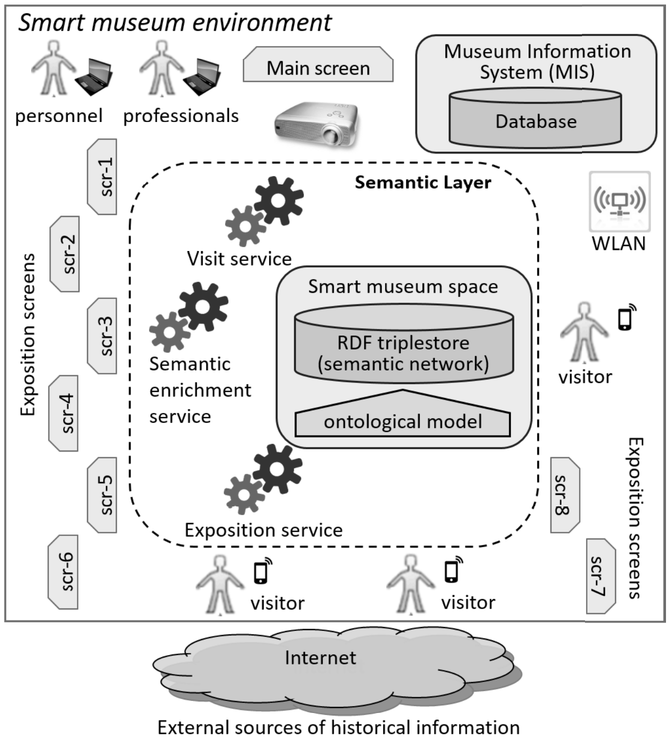

Fig. 2. Smart museum environment with access to the global Internet

represent semantic relations between them. The semantic network nodes represent exhibits, associated events, persons, and other historical objects.

The visit service uses the semantic network for search and analysis to construct personalized recommendations. Personalized recommendations make the provision of museum information to the visitor closer to her/his potential interest. The visit service provides recommendations for viewing the exhibits depending on the user preferences and current context. For example, consider the situation when group of guests from other countries came to the museum. Preliminary, before starting the visit, creation a "Visitor profile" can find the exhibits about the international cooperation and with the focus on guest country. The visit service will recommend exhibits associated with universities of visitors country. The result of the service is a personalized visit program.

Based on visitor profiles the exposition service visualizes information about exhibits from the visit program to the appropriate digital screens in the room.

The semantic enrichment service allows the users to add semantic annotations to exhibits. The users can be both museum personnel and museum visitors. Museum visitors can significantly enrich the museum collection of the information about available exhibits. The users have personal mobile devices and can access relevant information about surrounding devices.

Addition of semantic annotations is useful in several scenarios. Firstly, the visitor adds missing information about an object semantic web. Secondly, the visitor identifies relations between objects in the semantic network and adds these relations. This new information requires expertise from the museum personnel. As a result, museum personnel adds new descriptions to the MIS, and exhibit cards are updated to describe the objects in accordance with the requirements of the underlying MIS.

IV. SOFTWARE INFRASTRUCTURE

Let us consider solutions to implement the semantic layer using the smart spaces approach. We focus on the Smart-M3 platform, which provides appropriate technologies and development tools [22]. M3 stands for multi-device, multi-vendor, and multi-domain. We design a Smart-M3-based software infrastructure to implement the semantic layer of a smart museum as the multi-agent service-oriented information system deployed on the top of MIS. The semantic layer supports construction and delivery of the services based on the semantic network, as it was shown in the previous section.

The software infrastructure needs to be deployed on devices of a museum exhibition room, i.e., in a particular case of indoor localized IoT environment. The classes of IoT-enabled devices are summarized in Table I.

The software infrastructure of a smart museum consists of the semantic information broker (SIB) and those knowledge processors (KP) that are responsible for service construction and delivery [23]. The SIB is launched on a dedicated server machine. It realizes a shared information space in the form of a knowledge base with the use of Semantic Web technologies [24]. In particular, this knowledge base keeps the semantic network of museum exhibits and related information Each KP has network access to the SIB. Communication between KPs is indirect, i.e., it occurs through the insertion and removal of RDF triples into or from the SIB. The subscription operation allows KPs to detect changes of specific triples in the shared information space.

At the conceptual level, a smart spaces service is considered as knowledge reasoning over the shared information space and delivering the result to the users [25]. The focus is on agent-based (architectural) level, which describes the functioning of KPs that are involved in service construction and delivery. A service is constructed by either a single KP or is a result of interaction of several KPs.

In the considered case of a smart museum, the core semantic information services are semantic enrichment service, visit service, and exhibition service. The services carry out the construction and complement of the semantic network forming an information domain model. The nodes of semantic network correspond to exhibits and to other historical entities (e.g., persons, geographical points, buildings, events, etc). Let us consider each service in the context of interacting KPs that are involved in the service construction and delivery.

The semantic services are composed based on the known KP taxonomy with five classes for KP roles, see [26]. Combinations of different KP roles for services implementation are summarized in Table II. The functional role is an abstract description of the functional properties of KP. The role class determines the general principles for the implementation of the KP internal logic to operate with the shared information space.

A. *Visit service*

The visit service is responsible for construction of a visit program, its adaptation depending on the preferences of the museum visitor and dynamically changing conditions as well as for the visualization of the program on the main screen in the museum exhibition room. A visit program is a set of exhibits to be informational augmented on screens and

TABLE I. IoT-ENABLED DEVICES FOR THE SOFTWARE INFRASTRUCTURE

Class of devices	Description
Public multimedia devices	They include interactive screens, media projectors, and microphones installed in the exhibition room. The devices are primarily for service consumption by visualized provision of the information to the visitors. For instance, series of touch screens can show an interactive information about the exhibits.
Personal mobile devices	They include smartphones, tablets, and laptops carried individually by the visitors. The devices can be used for personalized service delivery and participation in the activity. For instance, personal mobile device gives to visitor the ability of watching a personalized list of exhibits.
Server machines	They are responsible for data storage and processing functions. Typically the devices are non-local, e.g., a server is in the corporate network or in the global Internet.
Local computers	They are responsible for service construction based on search and analysis of shared content in the semantic network. Typically, they are physically present in the room.
Smart IoT devices	They represent physical things augmenting them with processing and communication capabilities. For instance, a physically presented exhibit is equipped with an RFID tag to provide textual description for any close device.
Network communication devices	They create local area networks (LAN) such that all other participating devices can communicate locally as well as have access to external resources (e.g., to the global Internet).

TABLE II. KP TAXONOMY

Service	Functional role	Role class
Visit Service	Visit program	Adapter
	Visit maintenance	Aggregator & Controller
	Recommendation	Aggregator
Exhibition Service	Exhibition	Adapter
	Exhibition coordinator	Aggregator & Controller
Semantic enrichment service	External search	Filter
	MIS interface	Filter
	Semantic analysis	Aggregator & Controller
	Semantic enrichment	Controller

personal mobile devices. This service is constructed as a result of the interaction of KPs in accordance with Fig. 3. The idea of visualization of the program came from the screens available in the History Museum of PetrSU. Visualization software and accompanying exhibits is a convenient and usable solution, because a large part of objects of the History Museum of PetrSU is represented in digital form.

To initiate the construction of the service museum personnel make up the provisional visit program S from the available in the shared information space exhibits objects via specialized personnel client. Visit maintenance KP performs actions for dynamic compilation of visit program x_{vis} and organization of control actions to other KPs and services. For example, this KP can control visualization process v of visit program on the main screen, publishing notification for Visit program KP and implementing service delivery process d. Visit maintenance KP also provides personalized construction of visit program for each visitor using recommendations x_{rec} received from Recommendation KP based on the relationship context information of profiles x_{per} with information about the exhibits x_{exh} declared in the visit program.

Recommendation KP can be based on exhibits ranking, where each rank associates with the exhibits to describe the recommendation degree of (the higher rank the more recommendable). This KP can use various algorithms to calculate the rank of exhibit. In [27] authors consider methods of structural ranking. In our case, a variant of the well-known PageRank algorithm can be applied.

B. Exhibition service

The exhibition service performs selection of exhibits from the created visit program for formation of virtual exhibitions on a series of screens. This service is constructed as a result of the interaction of KPs in accordance with Fig. 4.

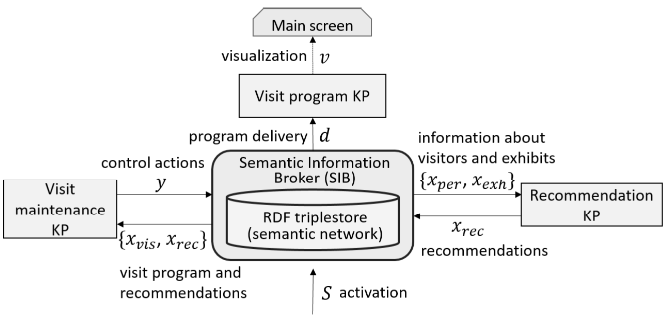

Fig. 3. Architectural KP-based design of Visit service

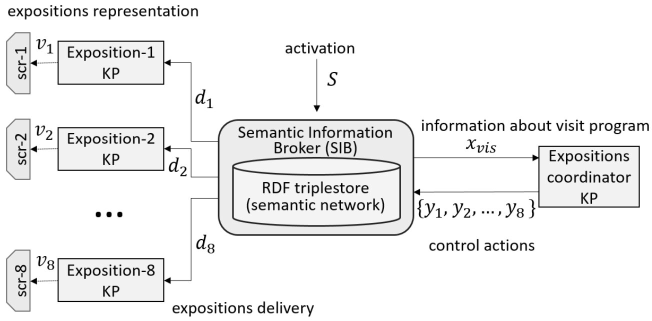

Fig. 4. Architectural KP-based design of Exposition service

The visit service controls activation of this service construction by publishing formed visit programs S together with special control notification in shared information space. Each Exhibition-n KP is responsible for presenting v_n specific set of media information d_n about the exhibits (for example, a photo, text or audio records, etc) on one of the eight screens, where n is number of screen. Exhibition coordinator KP determines the elements of each set and exhibition presentation time. This KP forms control actions y_n for the required Exhibition-n KP analyzing visit program x_{vis}.

C. Semantic enrichment service

Enrichment of the museum information model is the result of the semantic enrichment service. The sources of such information for the service are from (a) MIS, (b) Internet sources of historical information as DBpedia, YAGO, and Freebase, (c) exhibits themselves, and (d) from museum visitors, personnel and professionals. This service is constructed as a result of the interaction of KPs in accordance with Fig. 5.

Personnel and visitor clients form the control actions S for replenishment of a semantic network activating the service construction. The MIS interface KP provides an interface to the basic collection of cultural heritage object descriptions. This KP feeds the data flow of information objects as photos and interviews (speech or video records) d_{mis} from MIS in SIB.

The external search KP is responsible for interaction with the databases of DBpedia, YAGO, and Freebase services from the Internet. This KP feeds the shared information space with historical information d_{dbp} about existing exhibits.

The visitors and personnel (as historians) can add new information x_{inf} about surrounding exhibits as well as their relations to other cultural heritage objects and historical facts. In the visitor case, personal mobile client gives the ability to watch list of exhibits with their description, to record audio (video) with the comment to the exhibit, and to add text comment. The semantic enrichment KP analyzes the provided information to enrich the semantic network with more exhibits descriptions d_{exh} and relations d_{rel}.

The semantic analysis KP performs semantic information linking of exhibits in the semantic network. This KP extracts semantic network nodes x_{nod} representing exhibits, persons, and other historical objects. Then it builds semantic relations d_{rel} between them by means of semantic analysis algorithms.

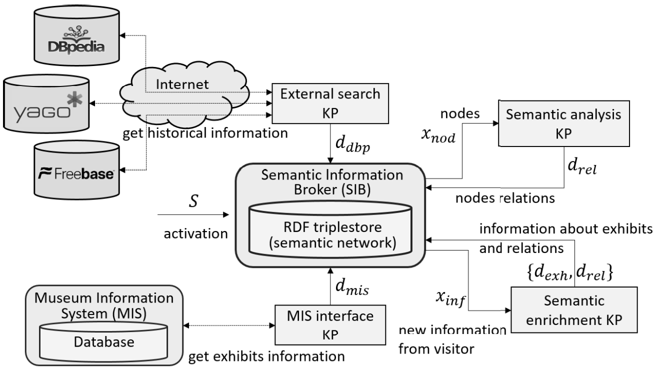

Fig. 5. Architectural KP-based design of Semantic Enrichment service

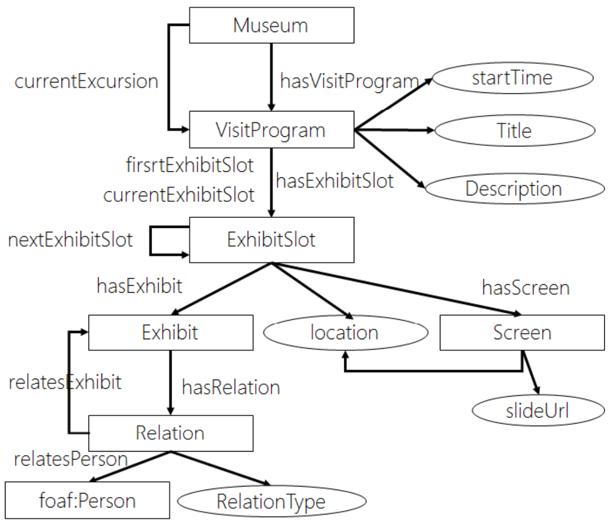

Fig. 6. Museum ontology class

V. Ontology for Semantic Layer

Our ontological model describes transitive objects relation in the smart space. The problem domain is everyday life history. The model defines the structure of a semantic network proposed for information representation and object linking.

Information objects related to the daily life of the university community of PetrSU has received special attention from museum personnel when creating ontology. We focus on developing the ontological model that uses already existed representation of exhibits in the museum system. The model makes possible building of semantic network with support of information ranking and semantic matching. Selection of the model for representation of exhibits from the museum system is left for our future work. In particular, the CIDOC conceptual reference model [16] can be used.

The main usage scenario lies in building personalized expositions. It includes a specific set of exhibits, which was selected for a visitor profile. Therefore, a model of ontological classes is necessary, which represents a list of exhibits and indicates possible relations between the current object and other exhibitions, which lie in field of visitor interests.

The ontology of the museum system in respect to the visit service is shown in Fig. 6. Ontology classes and data properties are described with square and ellipse shapes, correspondingly. The name for object properties are specified next to the arrow. Class Museum links all system objects together. The primary class property is connection with class VisitProgram. Class stores a title and description (Title and Description), exposition structure and time stamp (StartTime). Property firstExhibitSlot is a pointer on first planned exhibit and it is used to arrange the exposition structure. In the case of request optimization on obtaining a list with all exhibits, when order is not important, linking property hasExhibitSlot can be used.

Class ExhibitSlot is used for connection with the exhibit (hasExhibit), its location in the museum room (location) and screen with additional information (hasScreen). Data property location provides the text description of exhibit location in the museum room, e.g., the winners cup in the championship on programming located on the stand number 3, dedicated to the Faculty of Mathematics. A more formal way of location description in room with possibility of building optimal route is priority of our future research. Object property Screen stores information about location of screen, which used for displaying current slide about an exhibit.

To provide linking capabilities of exhibits we introduce class Relation. The given class available through property hasRelation of class Exhibit, that used to access all related to object links with other exhibits and persons (relatesExhibit and relatesPerson object properties correspondingly). To determine the type of binding, data property RelationType is used. This property expresses relation between objects, e.g., edition of the newspaper highlights events in the life of the university, which was attended by the current rector at that time.

To represent a visitor, class Person is used, following the FOAF specification. It allows accessing the name, image, age, topic of interest, and other properties. The class is shown on Fig. 7. Objects of class Person is used by class VisitorProfile for linking a person and system user through object property personInformation. This connection provides advanced search function for making new recommendations. Data properties username and password are used for the authentication.

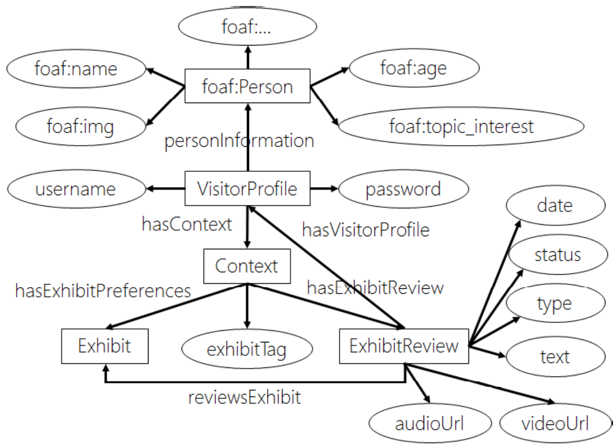

Fig. 7. Visitor Profile ontology class

TABLE III. NOTIFICATION MODEL FOR MUSEUM SCENARIOS

Name		Description
KP	Semantic Analysis	Carrying out additional analysis to discover new relations with appearance of new Exhibit.
Notification	newExhibit	
Parameter	Exhibit	
KP	Semantic Analysis	Carrying out additional analysis to discover new relations with appearance of new ExhibitReview.
Notification	newExhibitReview	
Parameter	ExhibitReview	
KP	Visit program	Screen content changing accordingly with parameter screenMode.
Notification	changeScreenMode	
Parameter	screenMode	
KP	Expositions coordinator	Changing current slide on screen.
Notification	changeSlide	
Parameter	slideUrl	

The important point for future semantic search is user context which is represented with object property hasContext. The user has preferences in the terms of interesting exhibits for her/him. User preferences are modeled with object property hasExhibitPreferences. Additionally, the user can contribute the list of interesting topics about exhibits in data property exhibitTag in manual or semiautomatic ways.

Visitor context provides access to his reviews by object property hasExhibitReview. Review stores with class ExhibitReview, which keeps references on audio and video files (audioUrl and videoUrl properties), textual notes (text), review type (type), moderation status of review (status) and posted date (date). References between a review and an exhibit are received through object property reviewExhibit. To enhance reception speed of all reviews to the exhibit, there is class Review, that is connection between the exhibit and all its reviews.

Interaction between the considered services and clients follows the notification model [28]. Whenever a service publishes data some other services are notified about changes due to subscription. The notification model describes a finite set of possible variants for services to interact with each other. Each service subscribes to its own notification types, each corresponds to interaction variant and represented as a set of RDF triples kept in the smart space.

Our variant of the notification model is shown in Table III All notifications act as one-to-one requests. The notification model can be extended with new one in case of unexpected scenarios.

We also apply an advanced variant of subscription with class VisitorClientActivity. This variant solves the task for notification of a concrete user about updates in her/his exhibits [29]. This subscription works in one-to-one way with ability of identification through property forVisitorProfile. Property status indicates on reception of the user notification and marks it as read.

VI. CONCLUSION

Although there are a lot of work on making museums smart by using the IoT advances, the approaches to use of rich semantics in service construction and delivery are still on their early stage. In this paper, we studied the semantic layer in respect to the smart museum concept and to the opportunities for constructing services that enhance the existing MIS. The semantic layer realizes connection between the involved actors (visitors and personnel) and shared cultural heritage knowledge (physical and virtual exhibits with related information). We developed a design of the semantic layer to implement the latter as a software infrastructure. The results form a suite of solutions that can be further implemented using the Smart-M3 platform. The solutions were analyzed in respect to the case study of the History Museum of PetrSU. The proposed solutions can serve as reference ones for development of other museum services as well as for other museums and cultural heritage areas.

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