

# An Ontology Engineering Approach to User Profiling for Virtual Tours of Museums and Galleries

W. A. Eardley, D. E. Ashe, and B. D. Fletcher

**Abstract**—This paper describes a study of the development of a hierarchical ontology for producing and maintaining personalized profiles to improve the experience of visitors to virtual art galleries and museums. The paper begins by describing some of the features of virtual exhibitions and offers examples of virtual tours that the reader may wish to examine in more detail. The paper then discusses the ontology engineering (OE) approach and domain modelling languages (e.g. KACTUS, SENSUS and METHONTOLOGY). It then follows a basic OE approach to define classes for a cultural heritage virtual tour and to produce a Visitor Profile Ontology that is hierarchical and has static and dynamic elements. It concludes by suggesting ways in which the ontology may be automated to provide a richer, more immersive personalized visitor experience.

**Index Terms**—Ontology engineering, virtual tour, personalization, profiling, domain modelling.

## I. INTRODUCTION

Virtual exhibitions and tours of art galleries and museums, whether web-based or merging the real world with the virtual one through using augmented reality [1] are becoming increasingly popular. Museums are moving away from conserving and displaying artefacts to focusing on an educational and entertaining social experience for the ‘visitor’ [2]. One significant fact about the prevalence of such online virtual tours is that in addition to entertaining the user they seek to impart knowledge and to provide a valid educational experience [3]. A trip to a museum or gallery has long been in the curriculum of most arts or science subjects at school and university. Virtual environments now open up more educational options and opportunities to acquire knowledge. Users (students, researchers and *aficionados*) can make ‘visits’ to museums and galleries that would not be possible in real life due to the constraints of time, cost and mobility.

Although physically moving around a gallery or museum has the advantage of being aesthetically appealing [4] the layout or display space of the exhibits may be limited or curtailed by the museum’s curators, due to the restoration or conservation of exhibits or the museum’s actual physical space, depth and size [5].

Some exhibits may even be too precious to put on public display. An online three-dimensional (3D) virtual museum, on the other hand, helps to promote the museum’s collections,

to extend the longevity of temporary or special exhibitions, encourages physical visits and provides non-stop remote access to a worldwide audience. In some virtual museums or galleries, visitors are able to follow a guided tour using interactive maps and examine virtual replicas of great masterpieces and valuable artefacts. Some even create their own virtual tour by navigating freely around the collection [6]. In addition, the visitor may be provided with a richer experience in an immersive environment, which is engaging, thought provoking and informative. In a real gallery or museum, the visitor is left with rich personal impressions of an emotional and intellectual experience, creating a memory, which may be evoked later [7]. It is important to replicate these emotions if the ‘full value’ of a virtual visit is to be obtained. This paper examines some types of gallery or museum online presence and suggests some ways in which the experience can be improved through ontology engineering (OE) and personalization.

The website ‘Virtualfreesites’ [8] currently includes over 300 sites that are described as ‘Museums, Exhibits, Points of Special Interest and Real-Time Journeys’ and offers ‘online guided tours on the Web’. The sites display a range of material from ‘flat’ text and images providing information about the museum or gallery and the exhibition and artefact to the type of rich, immersive experience described above. These sites use interactive multi-media featuring personalized content with sound and videos to ‘immerse’ the visitor. Two types of immersive experience are recognized, mental and physical. Mental immersion occurs when the visitor’s imagination is being pushed and defied, while physical immersion is achieved through the ‘realism’ of the virtual interface [5]. On the other hand, some virtual tours are in effect simply a way of introducing the features and attractions of the museum or gallery and preparing the user for an actual visit, while others use a mobile application to guide the visitor around the ‘real’ exhibition [9].

Popular virtual tours include conventional museums and galleries such as the Smithsonian Natural History Museum in Washington, D.C. [10], the Louvre Museum in Paris [11], and the Oxford University Museum of Natural History [12]. In addition, there are sites that feature exhibitions that are not site-specific but are grouped according to specific themes, such as the European Virtual Museum [13], which combines a collection of items from various museums in Europe into a series of virtual exhibitions as 3D images. This in effect creates the potential for a ‘real’ tour of a virtual museum, rather than a virtual tour of a ‘real’ museum. Other museums or galleries offer virtual experiences that do not seek to replicate a tour, but which display exhibits that meet the user’s preference of theme or type, such as the Rijksmuseum in

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Amsterdam [14].

## II. ONTOLOGY ENGINEERING

Ontologies have been used for some time in the fields of computer and information science as formal naming conventions and definitions of the properties, types and relationships between the entities that exist within a particular domain or ‘universe of discourse’ [15]. As such they have assisted in the categorization and definition (and therefore the understanding) of the things in which individuals and groups are interested and that influence their activities and dialogues [16]. As a comparison Neches [17] states that an ontology ‘defines the basic terms and relations comprising the *vocabulary* of a topic area as well as the *rules* for combining terms and relations to define extensions to the vocabulary’. This stresses the procedural aspect of an ontology as being equal to the lexical aspect. Since their development as a philosophical concept in the mid-1990s, ontologies have become important in academic areas such as knowledge representation, artificial intelligence and the semantic web. An ontology for an application such as a gallery or museum will contain an upper or top-level ontology, which describes very general concepts that are similar across all domains of knowledge and a domain ontology that contains attributes that are relevant to the domain of interest (e.g. archeology or fine art).

Studer [18] makes it clear that the terms in an ontology can be explicit (i.e. formally defined) or implicit if their intended meaning can be implied [19]. Hendler [20] refers to the ‘semantic interconnections’ and ‘rules of inference and logic’ in an ontology. This has important implications for the way in which knowledge is represented and for the language that is used to implement the ontology. Signore [21] classifies these domain ontology modelling methods as:

- *Highly informal* - described in natural language, which is understandable to humans but may not be machine readable;
- *Semi-informal* - represented by a restricted form of natural language e.g. Structured English or Gellish [22];
- *Semi-formal* – written in a specialised artificial language such as OWL [23];
- *Completely formal* – specified by rigorously defined terms with formal semantics, theorem proofs *etc.* [24].

Domain ontologies therefore constitute the ‘language’ for modelling domains and their processes and actors. They have been applied in library and archive management (e.g. the Dublin Core Schema [25]), galleries and museums (e.g. CIDOC CRM [26]) and personal relationships (e.g. FOAF [27]). OE is a way of constructing an ontology that follows a recognized iterative software lifecycle or engineering approach. Some examples of OE methodologies include:

- KACTUS [28], which follows a ‘bottom-up’ strategy and works by a process of abstraction, becoming more general at the higher levels and therefore capable of being adapted for other applications than those for which it was developed;
- SENSUS [29], which by contrast is a top-down approach for deriving domain specific ontologies from large sets of

data. SENSUS uses a tree structure to ‘fill in’ nodes until the ontology is complete. The approach promotes knowledge sharing, as the same root ontology can be developed into ontologies for different domains;

- Methontology, which is claimed [30] to be able to acquire the knowledge of the domain area and represent it by the creation of a vocabulary list or glossary. Developed using criteria set by an IEEE standard, it uses an iterative approach that includes three sets of activities: management (e.g. control, quality assurance and scheduling), development activities (e.g. specification, conceptualization, formalization) and support (e.g. knowledge acquisition, integration and evaluation). The life cycle includes the stages through which the ontology passes over time and the links it has with other ontologies.

The choice of an OE methodology for a gallery or museum project can be difficult for the following reasons [31]. Firstly, most OE methodologies are not mature and operable when compared to software engineering and knowledge engineering methodologies of the same generation. Secondly, many key software development activities are not included in OE lifecycles. Finally, OE methodologies are not unified and each applies its own standards and approach. In any case, once an OE methodology is applied, the ontology can be developed.

Generally, a gallery or museum application will have a core ontology (e.g. CIDOC CRM) and core metadata (e.g. Dublin Core). In such cases, the metadata will be in a highly informal or semi-informal language and the core ontology will be semi-formal or completely formal [21]. CIDOC is an object-oriented (OO) reference model that has an ontology of over 80 classes and over 130 unique properties, and ‘which describes in a formal language concepts and relations relevant to the documentation of cultural heritage’ [21]. The metadata can therefore be understood by humans, while the core ontology can be processed by automated tools, reasoning on the links between the user’s interests and preferences and the exhibits and the information about them. The adjective ‘semantic’ in this context implies that the semantic web can be used to import the data from any knowledge representation system and, by expressing the data and reasoning rules, to export the results onto the World Wide Web [21].

## III. PERSONALIZED VIRTUAL TOURS

The main advantage of a virtual exhibition is the opportunity to understand the visitor’s preferences (e.g. in terms of aesthetic themes and exhibits), his or her level of knowledge (e.g. novice or expert) and to ‘personalize’ the learning experience to the individual through interactive user modelling [32]. The aim of the long-running CHIP project at the Rijksmuseum is to:

‘...bridge the vocabulary gap and provide a user-driven approach for eliciting user’s (*sic*) preferences and characteristics, and recommend known/new information from the collection in a coherent and comprehensive way’.

(Wang, Aroyo, Stash and Rutledge. [32], P. 2).

In other words, to find out what the visitor *knows* (i.e. the

knowledge of the domain area), the visitor’s *interests* (i.e. the reason for ‘visiting’ the exhibition) and *understanding* (i.e. the level of expertise) and to use this information to provide and control access to exhibits that satisfy the user’s preferences. Research into personalization has been carried out for some time in the fields of artificial intelligence (AI), data retrieval and data mining [33]. It is recognized that online tours and exhibitions enable opportunities for providing a deeper experience to the virtual visitor by offering personalized services based on user profiling [34]. Many museums feature personalized tours and additional collections in their online presence. For instance, the CHIP project uses semantic web technology to provide personalized access to digital and real gallery and museum collections [35]. Cultural heritage personalization assists visitors in the selection and filtering of artworks and artefacts [34] to avoid information overload [36]. The amount of digital data that is presented online and the number and diversity of online visitors makes some form of adaptation imperative.

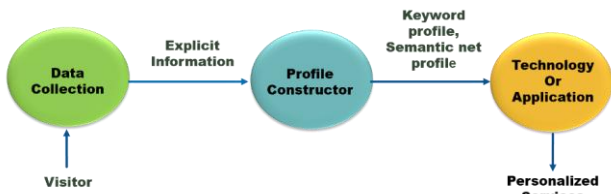


Fig. 1. Overview of visitor-profile-based personalization. (Based on and adapted from Gauch, Speratta, Chandramouli and Micarelli [33]).

Pechenizkiy and Calders [34] categorize adaptive systems into customized (adaptable) and personalized (adaptive). Customization is user-driven adaptation and refers to the ability of the visitor explicitly to change the visitor profile and to tailor the presentation of the content. Personalization is system-driven adaptation that aims to achieve the same ends

by user profiling [6]. According to Schiaffimo and Amandi [37], a basic user profile is vital information about an individual person. In the context of a museum, a profile is shown in overview form in Fig. 1.

In the data gathering phase of profiling, raw data is collected about the visitor either explicitly by direct human intervention or implicitly by automatically monitoring the user’s behavior and actions in the museum [33], [37]. In the profile construction phase, both types of data combine to form information that is input to profile constructor software. The visitor’s profile is therefore a record of his or her unique characteristics such as:

- *Socio-demographic characteristics* [38] - age, gender, occupation, education, impairments etc.;
- *‘Museological’ characteristics* [38] - purpose of visit, interest in museum topics, preferences of subject, prior knowledge, level of engagement with the topic, etc.;
- *Visit type* - individual types (e.g. casual, cursory or study) [39], group types (e.g. families, tourists or school parties etc.) [40], frequency of visit, duration of visit;
- *Psychological factors* - memory, learning style [41] cognitive style [42], visiting style [43] etc.

This is then stored, either as a keyword profile, a semantic net profile or a concept profile. By applying the profile to a technology solution or application, such as a recommender system [33] a personalized service can then be provided to the visitor to improve his or her experience [44]. If done effectively this can turn a monologue (‘the museum talking *to* the visitors’) into a dialogue (‘the museum talking *with* the visitors’). In this way the upper ontology (i.e. the things in the domain that all users are interested in or affected by) is augmented by an individual user profile (i.e. the user’s specific characteristics).

TABLE I: VISITOR PROFILE ONTOLOGY

Class_name	Class_description	Example_values
<b>Visitor</b>	Person visiting gallery or museum.	“name”, “address”, “contact details”.
<b>Visitor_profile</b>	Visitor’s basic demographic details	“age”, “gender”, “education”, “occupation”, “first language”, “impairments” [38].
<b>Visit</b>	Place of the current visit	“gallery reference”, “museum reference”, “gallery location”, “museum location”.
<b>Visit_type</b>	Classification of visitor according to group etc.	“solitary”, “pair”, “family group”, “friend group”, “club group”, “school group”, “tourist group” [40].
<b>Visit_motivation_type</b>	The purpose of the visit.	“education”, “enjoyment”, “study”.
<b>Visit_frequency_level</b>	How often the visitor has visited the gallery/museum.	“daily”, “weekly”, “monthly”, “annually”, “first visit”.
<b>Visit_duration_level</b>	Average time visitor spends in gallery/museum.	“brief”, “medium-term”, “long term”.
<b>Skills</b>	Attributes of visitor relevant to visits and topic.	“IT”, “interface”, “language”, “reading”.
<b>Skills_linguistic_type</b>	The visitor’s language of interaction (e.g. English).	“first language only”, “second language”, “multilingual”.
<b>Skills_reading_level</b>	The visitor’s ability to read in the ‘first language’.	“beginner”, “intermediate”, “advanced”.
<b>Skills_IT_level</b>	Visitor’s general IT proficiency.	“novice”, “intermediate”, “expert” [45].
<b>Skills_interface_level</b>	Visitor’s level of experience of using type of interface.	“novice”, “intermediate”, “expert” [45].
<b>Behaviour</b>	How the visitor behaves in relation to a visit.	“personality”, “learning”, “behaviour”, “movement”.
<b>Behaviour_personality_type</b>	Personal traits of the visitor (e.g. OCEAN or CANOE model).	“open-ness to experience”, “conscientiousness”, “extraversion”, “agreeableness”, “neuroticism” [37].

<b>Behaviour_learning_type</b>	How the visitor learns best (e.g. VARK model).	“visual”, “auditory”, “reading”, “kinaesthetic” [46].
<b>Behaviour_attitude_type</b>	How the visitor behaves on a visit in relation to the exhibits.	“busy”, “greedy”, “selective” [47].
<b>Behaviour_movement_type</b>	How the visitor moves around exhibitions and exhibits	“ant”, “fish”, “grasshopper”, “butterfly” [43].
<b>Interest</b>	What the visitor is most interested in.	“painting”, “sculpture”, “history”, “science”, “technology”, “geography”, “anthropology,”
<b>Interest_knowledge_level</b>	The visitor’s prior knowledge/experience of topic.	“superficial”, “developing”, “in-depth” [48].
<b>Interest_gallery_type</b>	Visitor’s topic of interest in art gallery.	“Renaissance”, “Neoclassicism”, “Romanticism”, “Modern”, “Contemporary,”
<b>Interest_museum_type</b>	Visitor’s topic of interest in museum.	“Prehistoric”, “ancient civilizations”, “Ancient Greece”, “Middle Ages”, “Industrial Revolution”, “America and the New World”
<b>Interest_exhibit_level</b>	Visitor’s interest in topic area.	“low”, “moderately low”, “moderate”, “moderately high”, “high,”
<b>Preference</b>	The type of establishment most visited by visitor.	“art gallery”, “museum”, “virtual gallery”, “virtual museum” .
<b>Preference_exhibition_size</b>	The scale of the exhibition preferred by visitor.	“small”, “medium”, “large,”
<b>Preference_room_layout</b>	The type of exhibition/room layout the visitor prefers.	“linear”, “open plan”, “free-flowing” [19].
<b>Context</b>	The visitor’s current situation.	“working”, “socialising”, “studying”, “leisure,”
<b>Time</b>	The date/time associated with the visitor’s session.	“minute”, “hour”, “date,”
<b>Location</b>	The visitor’s physical location.	“IP address”, “country”, “city”
<b>Activity</b>	What the visitor is doing.	“virtual tour”, “fact-finding”, “browsing,”

#### IV. APPLYING ONTOLOGY ENGINEERING

The first stage in applying the OE approach to a personalized gallery or museum application is constructing a visitor profile ontology as shown in Table I.

The first step, is to define the classes by providing them with unique identifier names (‘Class\_name’). The next step is to ensure that the ontology is understandable by including a narrative of the class (‘Class\_description’). Finally, a number of possible attributes of the class (‘Example\_values’) can be listed. Although in practice these would not be exclusive, as other class names and attributes can be added dynamically as the ontology adapted to its requirements through capturing additional implicit information by monitoring the visitor’s behavior and actions and as its ability to refine the personalized profile increases. This ability to combine static explicit information with dynamic implicit information makes profiling such a powerful tool for modelling visitor preferences and behavior. The greater the extent of personalization, the more enhanced will be the visitor experience and the greater his or her satisfaction with the virtual visit.

The next stage of the application is to construct the ontological structure as shown in Fig. 2, linking the key classes in the ontology [49].

This follows a top-down design approach, where ‘high level’ or general concepts relating to the visitor are captured (e.g. “education”, “impairments” etc.). The main class Visitor represents any user of a virtual gallery or museum and the VisitorProfile is the central class within the ontology. It links semantically to five key profile classes and decomposes into more detailed or specialized attributes or properties (e.g. Skills, Behaviour, Interest and Preference).

These top-level class attributes are further broken down into five top-level profile classes: VisitProfile, SkillsProfile, BehaviourProfile, InterestProfile and PreferenceProfile. Each of these profiles can be decomposed further into a series of second level classes based on their type, showing a property of the class or level, and indicating a measure (e.g. skills\_reading\_level and behaviour\_personality\_type). This ontology enables a dynamic profile of the visitor to be stored and maintained. For instance, the visitor’s virtual location can be updated continuously as he or she moves about the gallery or museum, and a pattern of movement can be applied to the profile. Also the visitor’s reading and linguistic levels can be updated dynamically when an improvement occurs or when a change is noted in the Skills\_linguistic\_level and Skills\_reading\_level in the SkillsProfile. The top-level classes function as follows:

- SkillsProfile relates to the visitor’s abilities in relation to his or her experience of the virtual visit (e.g. Skills\_linguistic\_level);
- BehaviourProfile holds useful facts about the way in which he or she approaches the virtual visit (e.g. Behaviour\_personality\_type);
- InterestProfile holds facts about the visitor’s topic(s) of interest within a virtual gallery or museum (e.g. Interest\_knowledge\_level);
- PreferenceProfile captures the visitor’s preferred exhibition layout (e.g. Preference\_exhibiton\_type).

There is a hierarchical relationship between the top and second level classes and the object and data properties for the top-level classes. For instance, each ‘Context’ hasTime, each ‘Activity’ hasLocation. This enables the ontology to keep a record of the visitor’s activities and the context within which they occur, allowing the ontology to be refined. Also the ontology can be automated semantically, e.g. by using the

Web Ontology Language OWL, and can be edited using the Protégé editor to maintain its hierarchical structure. Although beyond the scope of this paper, this offers some advantages:

- It allows reasoning about the ontology to take place, for instance updating the profiles or automatically classifying instances in classes;
- It includes automatic checking for the consistency of the ontology by detecting anomalies or unintended

relationships between classes;

- There are different ‘levels’ of OWL that can be tailored to different virtual gallery or museum applications. OWL Lite provides a basic classification hierarchy, Owl DL (Description Logic) offers greater computability and reasoning support and OWL Full allows greater semantic and syntactic expressiveness without the same degree of computability [21].

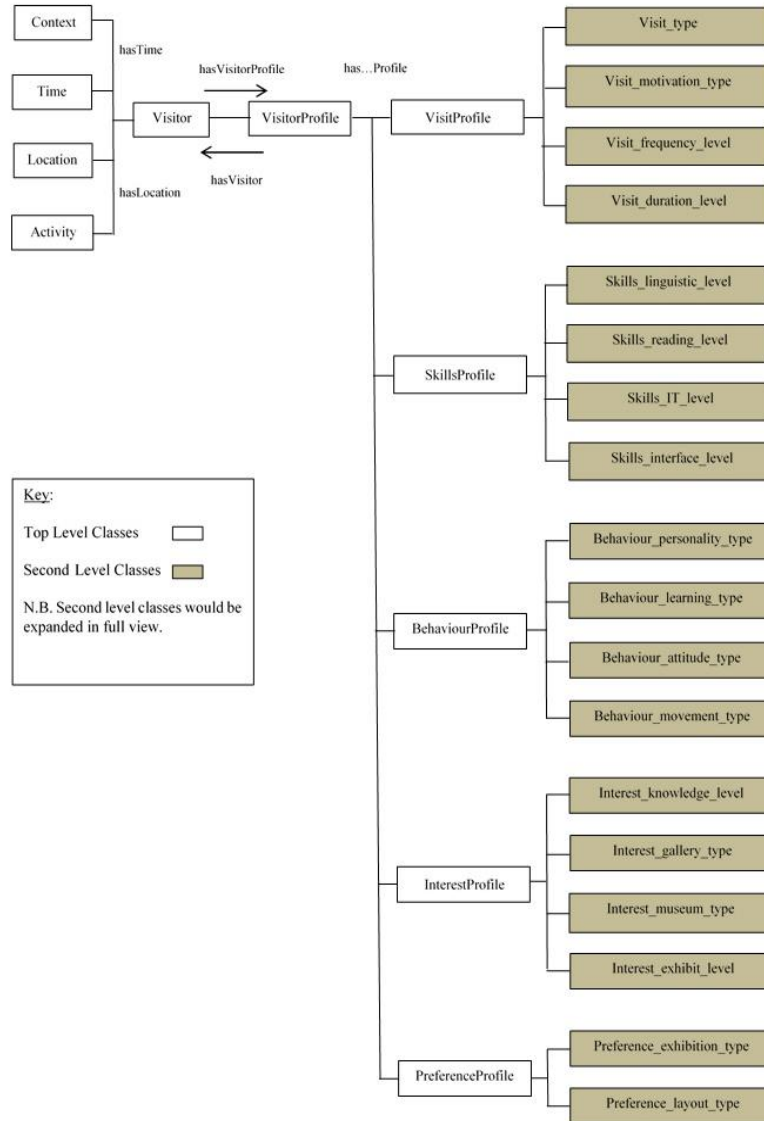


Fig. 2. Example of visitor profile ontology showing the hierarchical structure (Based on Skillen *et al.* [49]).

### V. CONCLUSIONS

It is the mission of a cultural heritage site to entertain as well as to educate its visitors. This applies no less to a virtual gallery or museum than to a real one. The experience of visitors to virtual galleries and museums can be enriched by a process of personalization based on an understanding of their visitor profile that enables content to be adapted according to their interests, preferences, skills and habits. This allows a dialogue to be established that can be likened to ‘talking *with* the visitor’ rather than ‘talking *to* the visitor’ as in a conventional guided tour. The research shows that there is potential in the OE approach to establish strong hierarchical

ontologies that describe well the visitors’ profiles and to provide a high degree of personalization. Future developments in the field could naturally embrace gamification of the explicit part of the static visitor profile (e.g. reward-based play) and the inclusion of artificial intelligence (AI) agents to gather implicit data in order to adapt the dynamic part of the visitor profile as the visitor progresses through the virtual exhibition.

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