Applying of an Ontology based Modeling Approach to Cultural Heritage Systems

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***Abstract*— Any virtual environment (VE) built in a classical way is dedicated to a very specific domain. Its modification or even adaptation to another domain requires an expensive human intervention measured in time and money. This way, the product, that means the VE, returns at the first phases of the development process. In a previous work we proposed an approach that combines domain ontologies and conceptual modeling to construct more accurate VEs. Our method is based on the description of the domain knowledge in a standard format and the assisted creation (using these pieces of knowledge) of the VE. This permits the explanation within the virtual reality (VR) simulation of the semantic of the whole context and of each object. This knowledge may be then transferred to the public users. In this paper we prove the effectiveness of our method on the construction process of an VE that simulates the organization of a Greek-Roman colony situated on the Black Sea coast and the economic and social activities of its people.**

***Index Terms*—Artificial intelligence, computer science, information system, virtual reality.**

I. Introduction

Developing a VE dedicated to cultural heritage system starts with the identification and explanation of the existing knowledge on a well delimited historical period. This knowledge concerns static concepts of the environment (such as pottery, clothes, tools, etc), and dynamic concepts as the population and their current activities performed (such as loading or unloading a ship, and so on).

The VE conception has to integrate both domain models, the corresponding 3D resources (geometries and animations), and multimedia. Here we focus on accomplishing the correspondence between each resource to a concept from models. Then, using an authoring tool, the user is assisted in the creation process of the context based on the pre-informed resources. It is necessary then to describe a scenario which is based on the created context and the activities described in the domain model.

The potential of using ontologies in the VR, as a mix between the advantages of new technologies and the strictness induced by the formalism, starts to be explored.

In the following we give a general view of some other approaches related to ours, and then, in section 3, we present the cultural heritage context of our efforts. In section 4 we briefly review our approach based on ontological and conceptual modeling to construct more accurate VEs. Section 5 is entirely dedicated to applying the proposed approach to cultural heritage environments. Our contribution ends with some conclusions and future directions of research.

This work was supported by PROMETEU grant AUF/2009 and TOMIS project PN II 11-041/ 2007.

Digital Object Identifier 10.4316/AECE.2011.03017

II. State of the Art

Taking into consideration that the variety of the virtual cultural heritage materials is enormous we have to organize them by using some conceptual and ontological modeling formalisms (such as UML models and ontology) which is finally completed with semantic meaning.

As result, the modeled context becomes more accessible to humans through agent-based situation simulation.

A. User side

The Museum24 project [1] uses an ontology based on information retrieval. Next to the used ontology manipulation and annotation functionality, the project has all the advantages of the popular CMSs, by combining the simplicity of these tagging services and the power of underlying ontology. The annotation is done by referring to ontology individuals that are created on demand.

In [2], the architectures modeling process is also considered from an ontological point of view. This way, an end user can accomplish modeling process in a much more natural way, by focusing on the semantic relations among different components instead of paying attention to geometrical details.

It is generally accepted that an ontology allows for constraining, expressing and analyzing the meaning of a shared vocabulary of concepts and relations in the project domain of knowledge. The Domus project explores the possibilities of using Semantic Web tools for representing and querying the complex relationships occurring among data in a cultural heritage domain [3,4]. To this end, an ontology is developed for describing relationship among artistic, botanic and zoological multimedia data by means of OWL (Web Ontology Language), while queries are expressed through the (far less standardized) ontology query language RDQL. Nevertheless, great inefficiency was experienced when using available Semantic Web tools, even in the execution of the simplest queries.

The VR-WISE project pushes further the limits of ontologies and uses them as the basis of conceptual modeling for VR [5]. This time, ontologies are used explicitly during the design process for representing specific domain knowledge, but also as general information representation formalism. By addressing to non VR-experts, VR-WISE proposes a conceptual specification as a high-level visual and intuitive description of a virtual environment. This approach, which brings together both the objects and the relations between them inside the environment, is followed by a mapping process through the domain and world ontologies in order to generate a VR specific application.

B. Agent side

In the realism of a simulated VE an important contribution arises from the virtual humans' behavior. From this perspective, efforts are made both in obtaining authoring tools for populating Cultural Heritage Environments with Interactive Virtual Humans [6], and in crowd simulation [7] (City of Pompeii). This kind of virtual human behavior animation gives the possibility to the simulated population to evolve without any interaction with the environment or between the virtual characters.

In [8] the authors accept the challenge of creating agents that display complex behaviors by interactions with other agents or with humans, as teams or as individuals, by considering VE as a normative multi-agent system. Doing so, the environment is formalized in terms of norms of acceptable behavior of participants, interaction protocols and roles of participants.

On the other side, by using a high level representation model, interactions between agents, or human and agents, may be described at a more abstract level and assertions about the virtual environment they inhabit become possible to the agents. This representation may be derived as annotations according to a particular ontology [9] or as result of mapping of a (sub)ontology dedicated to behavior of objects at the conceptual level into behavioral elements as intuitive actions [10]. The problem of action representation is brought into discussion in the context of consistency of integration of semantic representation in VR supporting the interleaving of simulation and interpretation [11].

III. MODELED ENVIRONMENT – THE TOMIS COLONY

The environment that we model is an ancient Greek-Roman colony situated on the Black Sea coast. Here, the main activities of the population take place around the harbor of the Tomis colony where we find different social classes of virtual humans, from sailors and merchants to simple individuals who are looking to buy goods from the local market. Of course, the place is also spiced by the existence of animals or technical devices used in market/harbor maneuvers, as ships, cranes, wheelbarrows, etc. All these elements are modeled by the means of virtual agents, as they are defined in [12].

We identified two types of virtual humans: one that asserts individual behavior, and that plays roles as Porter, Buyer, Merchant, Publican, Teamster; and another that asserts group behavior, and that plays roles as Group-Member, Soldier / Guardian (despite the fact that the agent behaves alone, it is part of the Group), as well as Rower, Pairs, Captain. At the level of group behaviors we adopted a boid-oriented solution [13], either by introducing a leader inside the hierarchies (as for Soldier / Rower and so on), or by letting the virtual agents to organize themselves (as for GroupMember) without necessarily having a leader. Examples of organized group behavior are present in different social activities such as business discussions, meetings between friends or people who go to work together. We identified three main aspects of this kind of behavior. The first aspect consists of the fact that the group members communicate which enables the very formation of the group. Secondly, they share a common route in their environment, feature which results from the first aspect. Last but not least, they occupy the same spatial region which separates them from the others and makes them act as a single entity. Military personnel may also form groups to patrol or guard objectives such as the city gates.

An example of organized economic activity is the process of supplying a commercial centre within the virtual environment. The roles involved in this activity are the Worker and the Salesman. This scenario takes place whenever a Salesman needs to sell goods which are missing from the market's stocks. As soon as the Salesman asks an available Worker to find the required goods, the latter starts searching for a depot which contains the merchandise. For this the Worker explores the stocks and if the goods are found they are picked up and carried back to the Salesman. After the goods have been received, they are made available for purchasing.

The market supply scenario makes it possible for other virtual individuals to purchase desired goods from that particular market, trading being one of the most important economic activities in the harbor area at that time, and even today.

IV. BRIEF DESCRIPTION OF THE USED METHOD

In [14] we presented an approach to construct VEs based on ontological and object-oriented conceptual modeling. In what follows we review our method. The approach is structured in three layers (see Fig. 1). The first layer consists of the static model of the context. The second layer completes the context description with dynamical aspects of the context. Finally, the third layer proves the consistency of the model by simulating a possible world as instance of the concept model.

A. The Model Layer

In order to explain the domain knowledge we use ontology languages such as OWL and SWRL that permit us a semantic description of the domain. The semantic descriptions, the ontologies, allow us to formally express WHAT exists in a real context from a structural point of view. In the same time we may describe WHAT is happening inside this environment due to the evolution of its components, as a result of human actions or not.

1) The ontology

A domain ontology can be constructed by extending a top-level ontology and other existing ontologies, i.e. the concepts of the domain ontology are subsumed [15] by concepts of the imported ontologies. For example, we created an ontology of the Tomis colony - Constanta, Romania today. Our ontology, at which we will refer to as the Tomis ontology from now on, uses concepts and relations of the DOLCE and D&S ontology, but also defines new concepts and relations [16, 17].

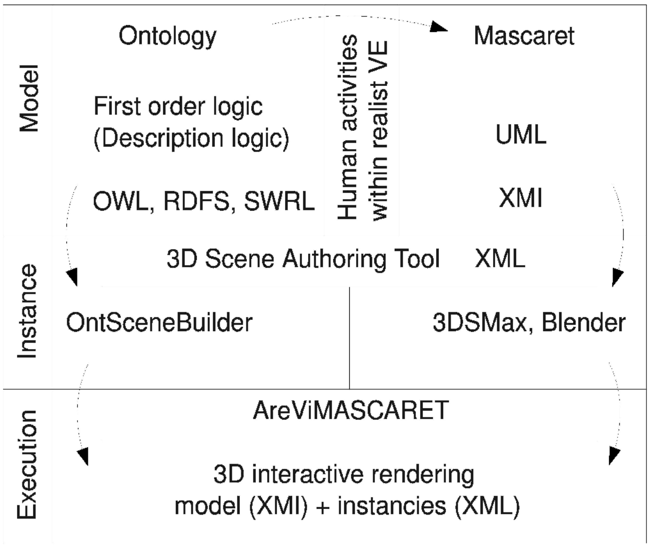

Figure 1. The conceptual view.

At this stage of the construction process, the Tomis ontology does not contain the ontology of the tasks which describe the activities or actions performed by the citizens of the Tomis colony. In order to enhance our ontology, we could use the DOLCE+D&S Plan ontology (DDPO) [18]. This ontology is based on the DOLCE and D&S ontologies and formally describes procedural knowledge, i.e. types of tasks, the order and frequency with which these tasks are performed. Due to its complexity, our approach proposes that this procedural knowledge should be semi-formally described using UML, and in particular MASCARET [19].

2) Mascaret

MASCARET represents an UML profile designed specifically for virtual environments. As UML MASCARET permits to represent the static aspects of the concepts involved in the environment thanks to the modeling concepts of classes, properties and relations. All the domain specific concepts described with MASCARET are then introspectable online during the simulation.

The dynamic aspects of the entities in the environment are designed in MASCARET by operations and state machines. Any complex operation can be described by an activity diagram so that all the steps of the execution are explicit in the simulation.

In MASCARET, these activities are designed using organizations, roles and procedures. Organizations are represented by UML Collaboration Diagrams which group together different roles. A role describes all the actions that the performer of the role may execute. The procedures are designed using activity diagrams which can be used to ontologically describe the tasks performed by virtual agents.

In D&S, a task is a course that sequences perdurants such as processes, events, accomplishments, states, and so on. Therefore, analyzing a MASCARET activity diagram we can identify and ontologically describe D&S actions, achievements and communication events.

In this way, we obtain a complete image concerning WHAT and HOW things are happening inside the environment. This information is the input for the second layer.

B. The Instance Layer

This second layer produces a particularization of the possible world formally described in the first layer. Here a mapping between the domain concepts and their representations in the virtual world is made using an authoring tool. To this end, we may choose between plug-ins for 3D professional tools such as 3DMax or Blender if the user is a professional, and OntSceneBuilder that addresses to domain experts [20].

Next, the user has access to an interface which is adaptable to context and permits the setting of some physical attributes (such as location) of the browsed concept, according to the ontology.

The interface output, exported as a XML file, contains information concerning the instances of the domain concepts. This file is then passed to an immersive interface.

C. The Execution Layer

In order to bring this snapshot of the domain to life, we are using ARéviMASCARET, an ARéVi based API that assures the multimodal 3D rendering of virtual worlds [21]. The virtual environment evolution is simulated as a direct effect of credible agent's behavior that populates the environment. In this situation, the high-level knowledge is accessible to the agent's behavior.

ARéViMASCARET provides a specific behavior to the agents in order for them to follow and perform the activities.

Each agent playing a role in the activity has its own knowledge of the evolution of the activity realization.

Each time an agent starts or stops an action it sends a message to all the agents playing a role in the activity. This allows to distribute the agent on several computers and to dynamically inhibit a role so that it can be played by a human.

V. Applying the Method

In this section we focus on our approach application in the construction of a VE that simulates the structure of the Tomis Colony and the behavior of its people.

A. Applying the Model Layer

In the DOLCE ontology, the concepts are classified in four main categories: endurants, perdurants, qualities and abstracts.

Endurants are particulars in space, which participate at least in one perdurant (e.g. substances, objects, social entities, concepts). For example, in the Tomis ontology we have different kinds of endurants such as ships, vessels, constructions, etc.

Perdurants are particulars in time (e.g. events, states, processes, phenomena), which have at least one participant, which is an endurant. For example, in the Tomis ontology, the Raise concept is defined as a process with two participants: the Yard and Halyard concepts.

Qualities are dependent particulars, "inherent" in either endurants or perdurants.

Abstracts are particulars in neither space nor time (e.g. sets, regions, metric spaces, quales, etc.). For example, the Shape concept (which is a physical quality) is related with the dolce: has-quale relation by each of the quale concepts: Cylindrical, Conic, Pointed and Circular.

The Descriptions-Situations ontology [17], shortly D&S, defines a theory aimed to support a first-order manipulation of theories and models. As the name indicates, D&S is based on a formal definition of the description and situation concepts.

MASCARET provides operational semantic for human activities so that these can be automatically executed in the simulation. For example, Fig. 3 shows the activity diagram of the ”Supplying a commercial centre” complex activity. As these activities are used in MASCARET to describe human activities, MASCARET provides an operational semantic founded upon the fact that there is no hard synchronization between actions realized by humans. The activities within a MASCARET activity diagram (see Fig. 3) are used to ontologically describe the tasks performed by a Salesman and a Worker to supply a market place.

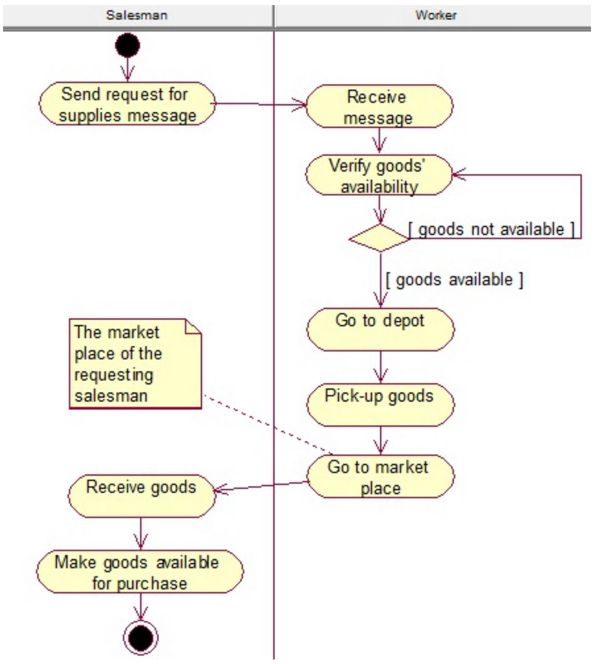

Figure 3. MASCARET activity diagram for ”Supplying a market place”.

In our case, “Put” is a D&S action in which the Person, Goods, Depot and Market concepts participate in (see Fig.4).

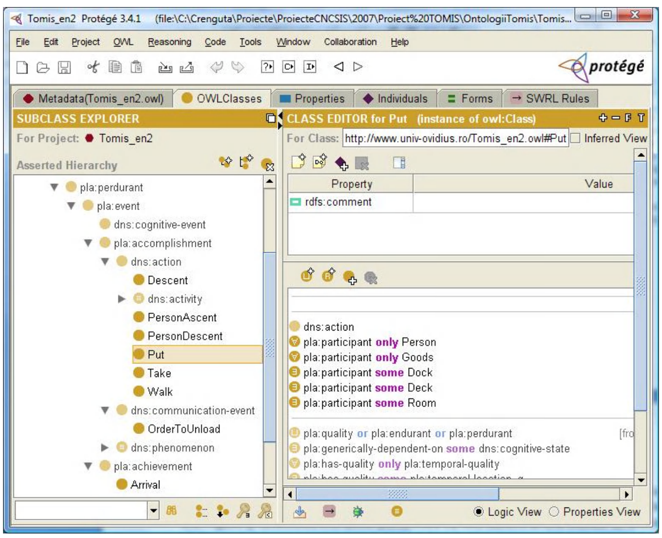

Figure 4. Some of the D&S actions of the Tomis ontology.

Spatial location of goods is changed such that they become included into the spatial region of another non-agentive physical object: depot, market. Another example of D&S action is the “Walk” concept that has as parts other actions: PersonDescent or PersonAscent and the Arrival achievement. The Walk concept also has a single participant: the Person concept.

B. Applying the Instance Layer

The domain expert interface allows the user to access one of the 3D models corresponding to the concept, in order to visualize it inside the VE.

Depending on the current general context, the user is permitted to coherently author the virtual environment.

The effect of the user’s actions is confirmed by the interface through 3D rendering of the artifact instance and in the case of OntSceneBuilder, by adding or updating the concepts tree.

Let us take as example an empty ship (Fig. 5.a). The user may select the ship (Fig. 5.b) and toggle the edit mode (Fig. 5.c) in order to modify the content of the ship. Then the user generates a cargo (Fig. 5.d) and then places (Fig. 5.e) the cargo inside the ship while in edit mode. When finished, the user can toggle back (Fig. 5.f) to navigation mode and use the ship together with its new contents.

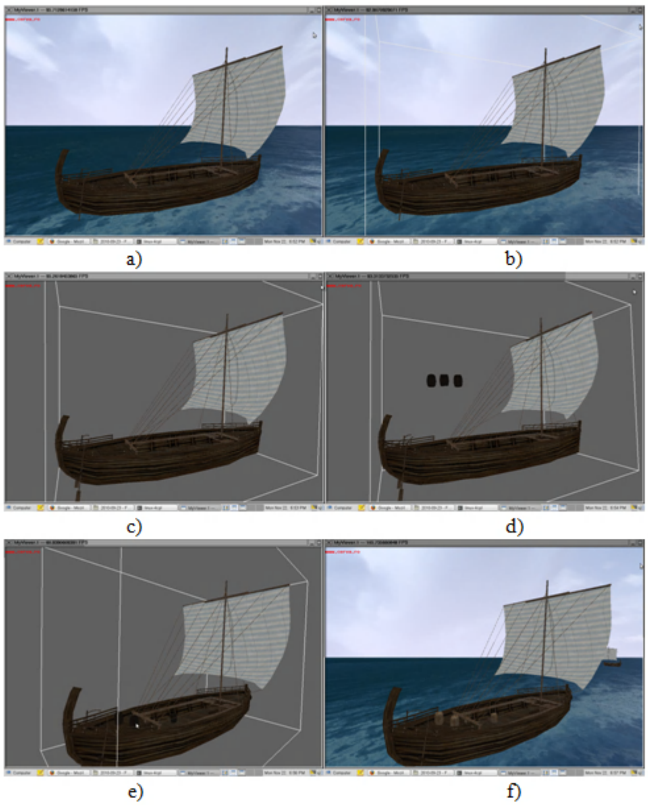

Figure 5. Editing an object’s structure.

The excerpts of XML files (Fig. 6) illustrate the changes to the internal structure of the environment, which result from the user’s actions over the ship showed in Fig. 5.

The XML also serves as a reference to the 3D models used by the VE. This makes it possible for users to change not only the position and orientation of the concepts but also their 3D representations.

C. Applying the Execution Layer

AReVi adopts an agent-oriented approach for 3D environment modeling. Entities are represented by reactive agents whose behavior is managed based on fuzzy cognitive maps (FCM). Each concept in a FCM has a corresponding simulated state machine.

This state machine reacts to external signals produced by changes in the environment's state.

```
<Entity url="./objXML/ship.xml" class="Ship">
    <Position x="6611.54390824" y="6796.43641845" z="934.218837791"/>
    <Orientation roll="0" pitch="0" yaw="-1.93231443353"/>
</Entity>
                                                                    world.xml
-----------------------------------------------------------------------------
<Ship>
  <Shape urlDet="./models/boats/ship_hi.wrl"
         urlMid="./models/boats/ship_mid.wrl"
         urlLow="./models/boats/ship_low.wrl"/>
  <Content size="3">
    <Object url="./objXML/barrel.xml" class="Entity">
      <Position x="88.1695534273" y="-19.2300085972" z="-39.4666019657"/>
      <Orientation roll="1.543811519" pitch="0.0327528612869" yaw="-1.39966133115"/>
    </Object>
    <Object url="./objXML/barrel.xml" class="Entity">
      <Position x="105.263441889" y="13.4633793947" z="-35.4836425296"/>
      <Orientation roll="1.61591832976" pitch="-0.0273858525496" yaw="-2.36637803158"/>
    </Object>
    <Object url="./objXML/barrel.xml" class="Entity">
      <Position x="-83.8014679761" y="-11.9669312355" z="-48.7882891406"/>
      <Orientation roll="1.52526221478" pitch="0.181045804926" yaw="-1.36636830893"/>
    </Object>
  </Content>
</Ship>
                                                                    ship.xml
-----------------------------------------------------------------------------
<Entity>
    <Shape urlDet="./models/cargo/barrel_hi.wrl"
           urlMid="./models/cargo/barrel_mid.wrl"
           urlLow="./models/cargo/barrel_low.wrl"/>
</Entity>
                                                                    barrel.xml
```

Figure 6. Excerpts from world.xml, ship.xml and barrel.xml.

The environment's evolution emerges as a reaction of other entities or due to actions done by agents playing a role in an activity. Each role can only be played by agents who possess the required capabilities.

For example, the "Supplying of a market place" procedure starts with the Salesman who signals the need for supplies.

If the required goods are available within the stock, agents who play the Worker role, and are not engaged in another activity, are assigned a task of finding the specified merchandise and distributing it to the market place. This scenario was conceptually modeled in the activity diagram of the Fig. 3 and is described in the following.

The Salesman sends a message to the environment in which supplies of different types are requested. If not performing another task, the Worker accepts the message. If requested merchandise is available within the stocks, the Worker calculates the shortest route to the depot that contains the required goods, and heads toward it. The Worker then reaches targeted depot, stops and performs the pick-up maneuver. The shortest route is calculated toward the market from which the message had originated, and the Worker starts to deliver the goods. When the targeted market is reached, the Worker stops and performs the drop maneuver. The Salesman receives the requested goods and makes them available for purchase within the market. The Worker is now relieved of duty and becomes available for other tasks.

Workers who can receive the supply task must be able to perform the pick-up and drop maneuvers. For example, in order to realize the activities required for this scenario, every Worker must perform the basic actions (Fig. 7).

The VE is designed in such a way that depending on the available animation files associated with the geometry of each virtual human, a particular individual may or may not be able to express certain behaviors.

Figure 7. Execution of the "Supplying a market place" activity in ARéViMASCARET.

Figure 7 illustrates the creation of the animations used in the "Supplying a market place" scenario using Motion-Capture technology [22]. Once created, these animation files are used by all virtual characters which must perform a certain activity at a given moment in time.

By using this technology, the resulting animations appear more natural to the beholder and therefore the VE in which they are used becomes more credible.

The real users are better immersed into the VE's evolution by the means of intuitive interaction devices, either as spectators or as active actors who can assume a role described in the activities from the domain model.

VI. CONCLUSION

We consider that mixing ontologies with object-oriented methodology can push forward the modeling process of VEs.

To prove this, we presented a way of applying such an approach that permits the reiteration of knowledge inside the VEs in order to be transmitted to the end users.

The credibility of the user experience in the generated environment is augmented by the behavior realism of the virtual humans that the user meets. Moreover, this user-oriented experience became more engaging by involving the user to actively take part at the virtual environment evolution by playing a virtual human role.

Our attention is now focused on the virtual agents' capability to reason on the basis of the domain ontology and to obtain semantic meaning of their actions inside the virtual environment.

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