Ontology Based Modeling of 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. Our proposal 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. Moreover, we may capitalize the knowledge concerning the environment resources (both geometrical and semantic) and sharing them between different VEs.** [*]

***Index Terms* — Virtual reality, artificial intelligence, information system**

I. INTRODUCTION

Developing a VE dedicated to cultural heritage system starts with the identification and explanation of the existed knowledge on a well delimited historical period. This knowledge concerns static elements of the environment (such as pottery, clothes, tools, etc), and dynamic elements 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 our, and then, in section 3, we present the cultural heritage context of our efforts. Section 4 is entirely dedicated to the proposed approach of ontology based modeling of cultural heritage environment. Our contribution ends with some conclusions and future directions of research.

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 became useful for human information that is improved with agent-based situation simulation.

A. User side

Museum24 project uses an ontology based on information retrieval. Next to the used ontology manipulation and annotation functionality, the project has all the advantage 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 [1].

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

It is generally accepted that ontology allows for constraining, expressing and analyzing the meaning of a shared vocabulary of concepts and relations in the project domain of knowledge. 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, 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 standard) ontology query language RDQL. On the other side, it was experimented the extreme inefficiency of the available Semantic Web tools, even in the execution of the simplest queries.

VR-WISE project pushes further the limits of the ontologies and use 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

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formalism. By addressing to non VR-experts, VR-WISE propose a conceptual specification as a high-level visual and intuitive description of a virtual environment. This approach, that 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] it is accepted the challenge of creation of 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 of representation model, interactions between agents, or human and agents, may be described at a more abstract level, assertions about the virtual environment they inhabit became possible to the agents. This representation may be derived as annotations according to a particular ontology [9], 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 FORTRESS

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 Tomis colony harbor site where we find different social classes of virtual humans, from sailors and merchants to simple individuals who are looking to buy some market products. 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 he behaves alone, he 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 ...), either by letting the virtual agents to organize themselves (as for GroupMember) without having necessary a leader.

To exemplify such an action we chose the "*Unloading a ship*" process. We consider that the Shipowner will supervise this activity. There will be two agents that play the Sailor role, one who searches the goods inside the boat and the other who takes these goods and places them on the dock. We still suppose that there will be another agent that plays the role of harbor Worker, and is in charge with deposing the goods in the right place, it means in a dedicated room. The process starts with a order of the owner of the ship for the other agents to "*unload my ship*". The agents react according to their responsibilities and once they found a good in their area of interest, usually an Unloading or Storage Area, they act by taking the goods from there and move it in another place.

IV. PROPOSED METHOD

Our approach combines the formalism of ontologies and object-oriented conceptual modeling and is proved by the mean of VR technologies. The approach is structured in three layers (see Fig. 1). The first layer consists of the static model of the context, then the second layer completes the context description with dynamical aspects of the context live. Finally, the third layer proves the consistency of the model by simulating a possible world as instance of the concept model.

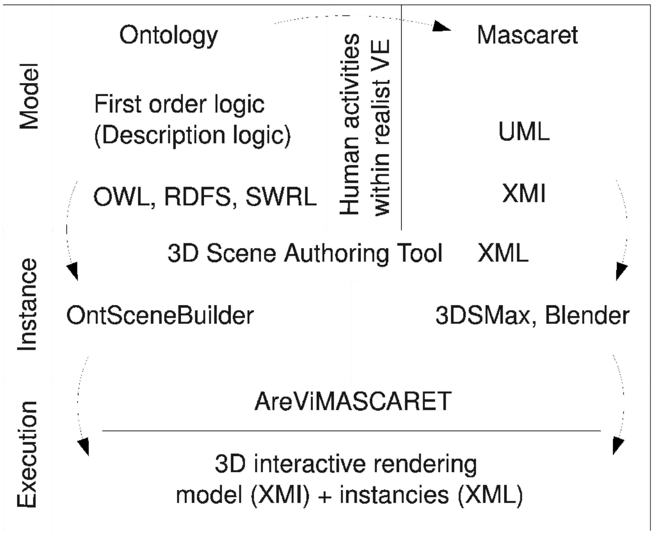


Figure 1. The conceptual view.

A. THE MODEL LAYER

In order to explain the domain knowledge we use ontology languages as OWL and SWRL that permit us a semantic description of the domain. 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.

A domain ontology can be constructed extending a top-level ontology and other existing ontologies, i.e. the concepts of the domain ontology are subsumed [14] by concepts of the imported ontologies. For example, we created an ontology of the Tomis fortress - 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 [15].

DOLCE is a top-level ontology, i.e. it describes very general concepts like space, time, matter, object, event, process, state, etc., i.e. independent concepts by a particular domain or problem [14]. According to DOLCE, the entities (particulars) which exist or existed in a real or imagined world are classified in concepts (categories) that are subsumed by four categories: endurants (continuants), perdurants (occurences), qualities and abstract.

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. In the Fig. 2 we present the taxonomy of the ships: Liburna and Trireme, and a part of the taxonomy of vessels: Amphora, Cup, and so on.

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. For example, the Depth, Length, and Width concepts are physical qualities of the Liburna concept (Fig. 2).

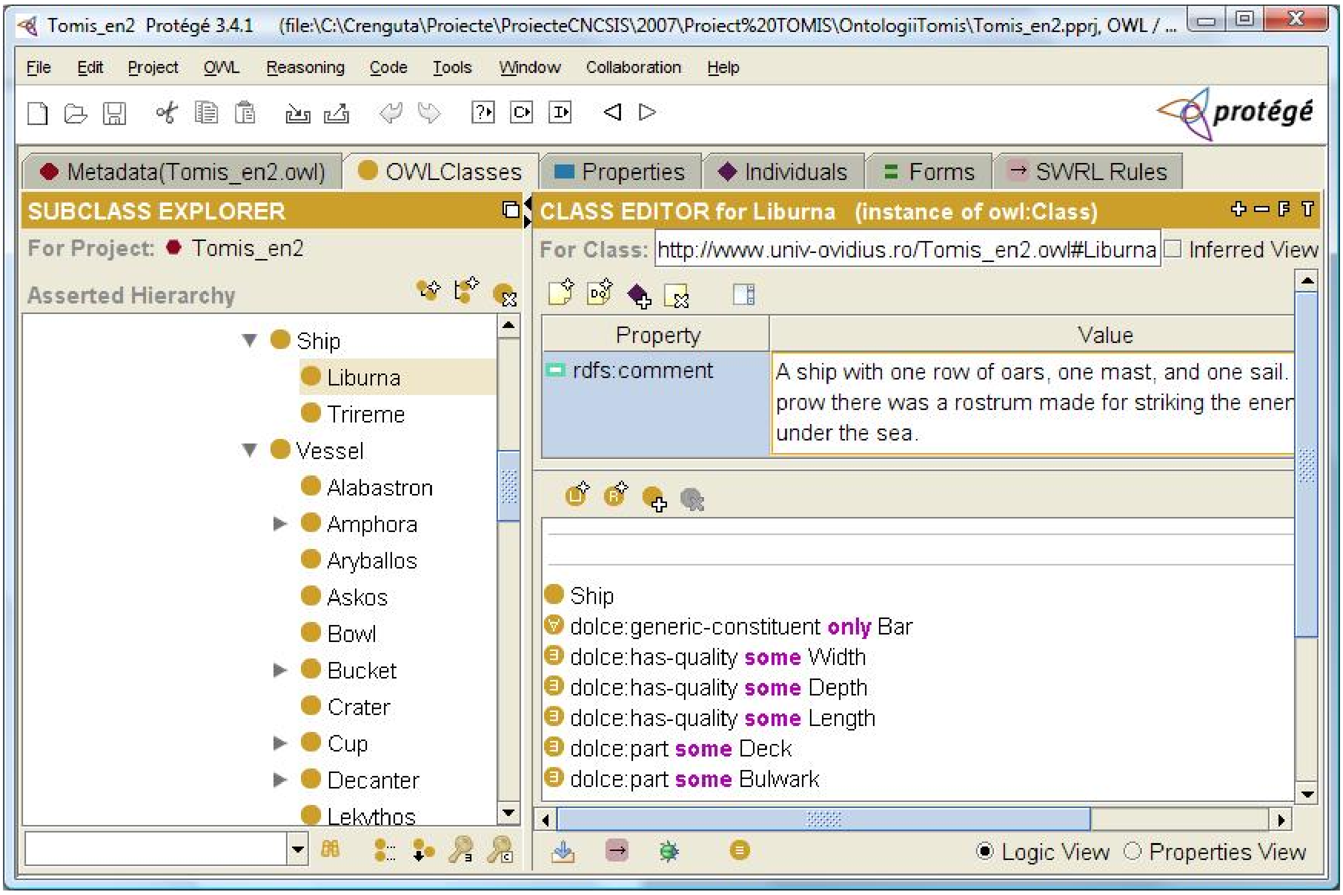


Figure 2. Excerpt of the Tomis ontology.

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 [16], 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.

A description is a non-physical object which represents an interpretation of a state-of-affairs in a nonphysical context; hence it is generically dependent on some agent and communicable. A description can define or use a Concept. In D&S the Concept category is subsumed by the Role, Course and Parameter categories, after the particulars classified: endurants, perdurants and regions. For example, in the Tomis ontology the Shipowner, Sailor and Worker roles are played by persons and are subsumed by the dns:status category, those individuals are roles that involve responsibilities, i.e. duties and rights in order to perform some task.

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 fortress. In order to enhance our ontology, we could use the DOLCE+D&S Plan ontology (DDPO) [17]. This ontology is based on the DOLCE and D&S ontologies and formally describe 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 [18].

MASCARET is a kind of 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 aspect of the entities in the environment are designed in MASCARET by operations and state machines. Any operation can be described by an activity diagram so that all the steps of the execution are explicit in the simulation or by OpaqueBehavior implemented by optimized programming code. The reactive behavior of the entity is designed by a state machine.

MASCARET provides operational semantic for those activities and state machine so that it can automatically be executed in the simulation. In our case what interested us is to study how we can describe human activities in virtual environments.

In MASCARET, those activities are designed by organizations, roles and procedures.

Organizations are represented by UML Collaboration which organized the different roles. A role describes all the actions that the performer of the role could have to execute. In MASCARET, the role can be played by an agent or by a person.

The procedures are designed by activity diagrams.

Partitions (or swim lanes) represent the roles involved in the procedure and their activities. In each partition, the actions to be played by the performer are organized by the control modeling elements: branch, sequence, fork and join. The achievement of an action depends on the kind of performer: agent or person. A first interest of using UML activities to design the procedures is that UML is a unified language that permits to describe the human activities in the same language that the domain model is designed. Then it is easier to express how the procedures manipulate the environment. A second interest is that UML activities are quite expressive to describe human activities. Like others language (HPTS, PetriNet, and so on) it is possible to use sequences, parallelism, choices and junctions.

For example, Fig. 3 shows the activity diagram of the ”*Unloading a ship*” 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.

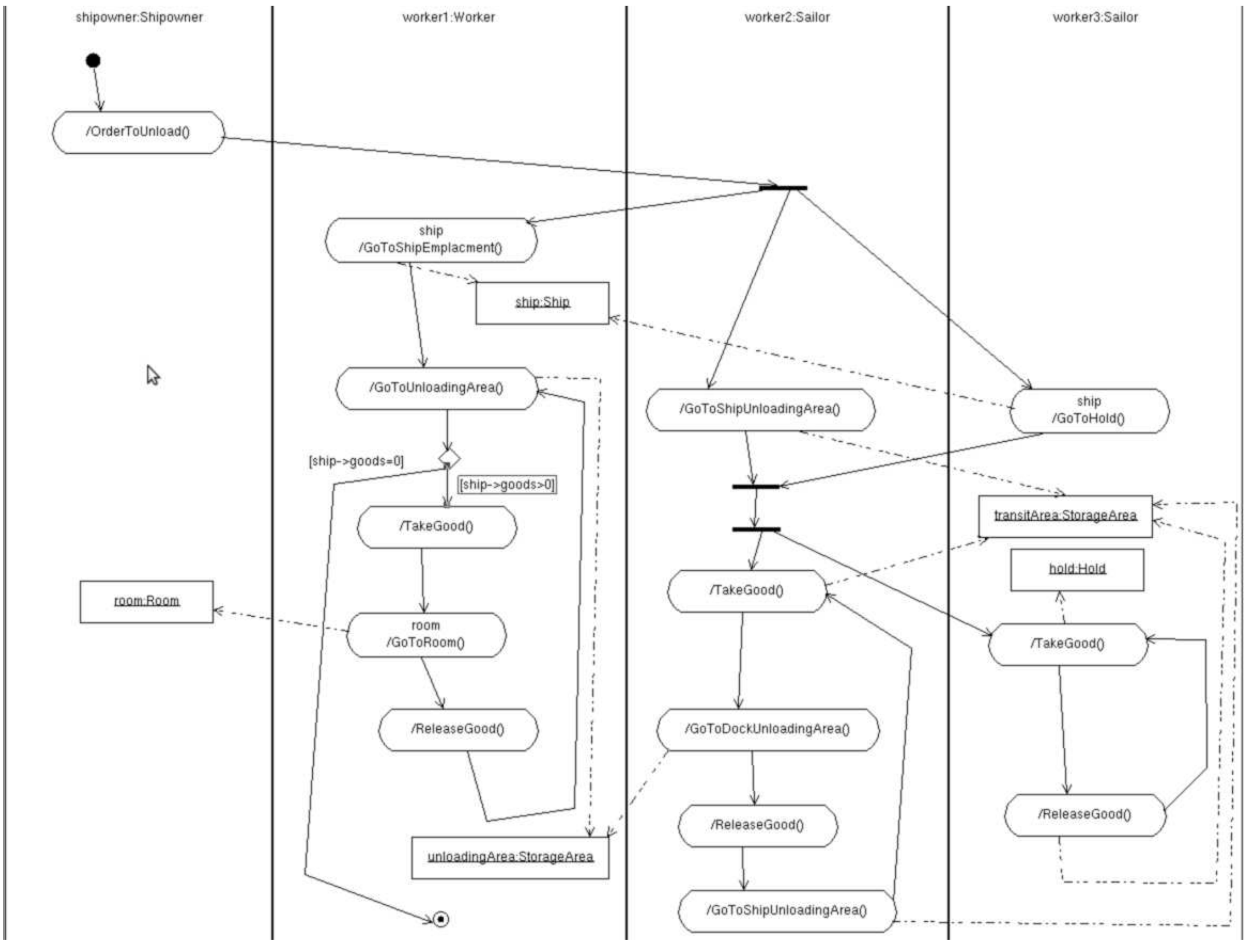


Figure 3. MASCARET activity diagram for ”Unloading a ship”.

More, UML gives a way to extend the semantics of the control nodes so it is possible to modify the way that these nodes are automatically interpreted in MASCARET.

MASCARET provides an agent behavior so that agents are able to participate and execute the procedure.

The activities of a MASCARET activity diagram of the

Fig. 3 could be used to ontologically describe the tasks performed by two sailors and a worker to unload a ship.

In D&S a task is a course that sequences perdurants such as processes, events, accomplishments, states, and so on. Therefore, analyzing the activity diagram of Fig. 3 we identified and ontologically described mainly D&S actions, but also achievements and a communication event.

For example, Put is a D&S action in which both the Person and Goods, and Deck, Dock, or Room concepts participate in (see the Fig. 4) and the spatial region of goods is changed such that the new spatial location is included in the spatial location of another non-agentive physical object: deck, dock or room. Another example of a D&S action is the Walk concept that has as parts another action: PersonDescent or PersonAscent and the Arrival achievement. The Walk concept has also a single participant: the Person concept.

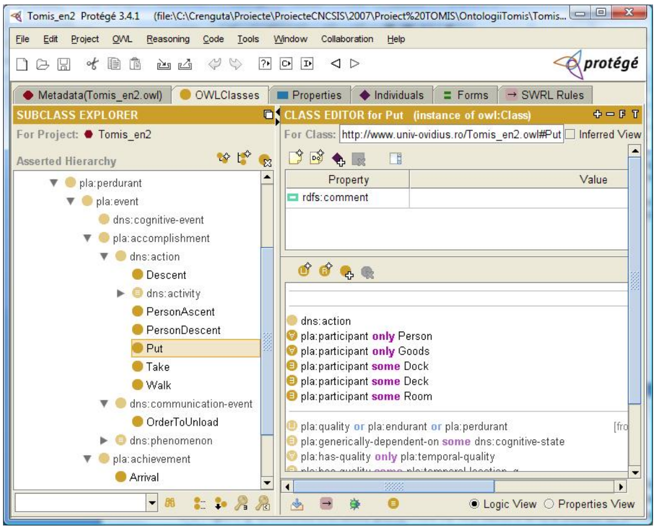


Figure 4. Some of the D&S actions of the Tomis ontology.

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

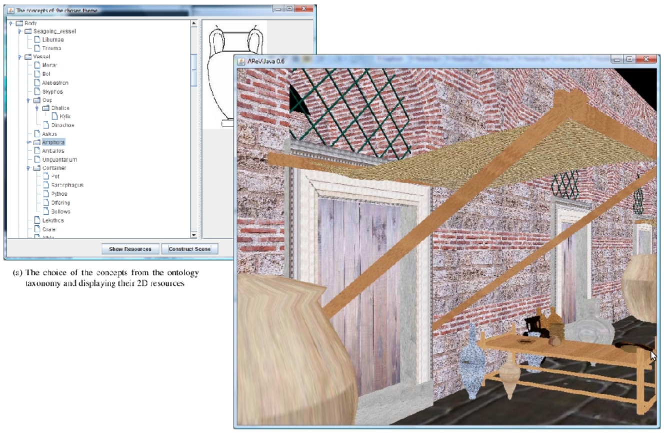
A. THE INSTANCE LAYER

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 plugins for 3D professional tools as 3DMax or Blender if the user is a professional, and, OntSceneBuilder that addresses to domain experts [19].

Next, an adaptable to context interface that permits the user to set some physical attributes (as location) of the browsed concept, according to the ontology, is available to the user. Then, the same interface allows the user to access one of the 3D models corresponding to the concept, in order to visualize it inside the VE.

This way, depending on the current general context, the user is permitted to add only coherent context. The effect of the user's actions is confirmed by the interface by 3D rendering of the artifact instance (right side of the Fig. 5) and, in the case of OntSceneBuilder, by adding or updating the concepts tree (left side of the Fig. 5).

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



(a) The choice of the concepts from the ontology taxonomy and displaying their 2D resources

(b) Displaying of a virtual scene

Figure 5. OntSceneBuilder screenshots.

B. THE EXECUTION LAYER

In order to bring to life this snapshoot of the domain, we are using ARéviMASCARET, an ARéVi based API that assures the multimodal 3D rendering of virtual worlds (see Fig. 6) [20]. 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.

Entities are represented by reactive agents whose behavior is simulated by a state machine. This state machine reacts on external signals and changed conditions which can be send as a reaction of other entities or by action done by agents playing a role in an activity.

ARéViMASCARET provides a specific behavior to the agents to be able to follow and realize the activities.

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

Figure 6. Execution of the "Unloading a ship" activity in ARéViMASCARET.

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

The real users are involved in the environment evolution by the mean of intuitive interaction devices, either as spectators, or as active actors by assuming a role described in the activities from the domain model.

V. CONCLUSION

We presented an approach that permits the reiteration of knowledge inside the virtual environments in order to be transmitted to environment's users.

By mixing ontologies with semantic meaning instilled by object-oriented design methodology, we make a step forward in modeling process of virtual environments and virtual agents that populate and behaves inside these environments.

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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