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Execution infrastructure for normative virtual environments

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ABSTRACT

Virtual Institutions (VIs) have proven to be adequate to engineer applications where participants can be humans and software agents. VIs combine Electronic Institutions (EIs) and 3D Virtual Worlds (VWs). In this context, Electronic Institutions are used to establish the regulations that structure interactions and support software agent participation while Virtual Worlds facilitate human participation. In this paper we propose Virtual Institution eXEcution Environment (VIXEE) as an innovative communication infrastructure for VIs. Using VIXEE to connect Virtual Worlds and EI opens EI to humans, providing a fully operational and comprehensive environment. The main features of the infrastructure are (i) the causal connection between Virtual Worlds and Electronic Institutions, (ii) the automatic generation and update of the VIs' 3D visualization and (iii) the simultaneous participation of users from different virtual world platforms. We illustrate the execution of VIXEE system in a simple eAuction house example and use this example to evaluate the performance of our solution.

1. Introduction and motivation

Nowadays there is an increasing demand for e-* applications (where * stands for learning, commerce, government, etc.). These applications support the participation of humans that engage in different activities, to achieve their goals. Whenever some tasks can be delegated and automated, these applications can be enriched with software agents. As a consequence, human and agent interaction must be handled. The internet based and distributed software technologies, such as Virtual Worlds (VW) and Multiagent Systems (MAS), may support the engineering of this type of applications.

Specifically, we advocate to take a MAS approach for designing these systems and to use 3D Virtual Worlds (Bartle, 2003; Messinger et al., 2009) to get humans-in-the-loop by facilitating their participation in the system. First, a 3D real-time representation of the system facilitates a better understanding of what is happening at both agent and the entire system levels. Second, thanks to the regulation imposed by the MAS, the 3D environment becomes a normative Virtual World, where norms are enforced at runtime. This automatic regulation contrasts with the way it is done in current virtual worlds where norms are restricted to the user's acceptance of the terms of service. Third, system participants can be both humans and software agents. In other words, it is an effective way to facilitate direct participation of humans in MAS, instead of just allowing them to customize agent templates with their preferences. This approach is taken in Virtual Institutions (Bogdanovych et al., 2005), which have proven (Seidel, 2010; Bogdanovych, 2007; Bogdanovych et al., 2009, 2011) to be an adequate platform to support this type of hybrid multi-agent systems, by combining Electronic Institutions (EI) (Esteva, 2003), which is an Organization-Centered MAS (OCMAS), and 3D Virtual Worlds. In this context, Electronic Institutions are used to establish the regulations that structure interactions and support software agent participation while virtual worlds facilitate human participation. The former focuses on the definition of the institutional rules that structure participants interactions. The later is related to the 3D virtual world and supports immersive human participation on the system by controlling an avatar in a 3D representation of the institution.

The formal specification of an Electronic Institution establishes a common *ontology* and the *roles* participants may play. The *performative structure* defines the activities participants can engage on and the relationships among them. This is specified as a graph, where *nodes* are *scenes* and *transitions*, and *arcs* connecting them are labelled with the roles that can progress through them. While scenes define interaction protocols (i.e. scene protocols) among participants by specifying the illocutions that can be uttered, transitions are used to model synchronization, parallelization, and choice points. Finally, *norms* define the consequences of agents' actions expressed as obligations.

A performative structure of an EI is used by our Virtual World Grammar (VWG) (Trescak et al., 2010) to automatically generate the virtual world design. Activities of performative structure are displayed as virtual spaces, while illocutions from the scene

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protocols are transformed to specific world interactions and gestures. Also, Virtual World Grammar mechanism allows to generate virtual world model for several different virtual worlds (e.g. Open Wonderland, Second Life).

Nevertheless, the generated design is only a 3D model of a virtual world, a visual layer, separated from the EI runtime infrastructure (called AMELI), the normative control layer. This separation does not allow normative control of world interactions at run-time. Thus, layers have to be connected, and in a way that would assure their consistent state according to the other layer. Therefore, the desired connection has to keep their causal dependence, when related actions in virtual worlds are processed by EI and related EI events are visualized in a virtual world, by manipulating the virtual world design (e.g. opening doors). However, with the existence of such a large number of virtual worlds, it is often practical to let participate users from several different virtual worlds. This increases the possible user base or allows to perform experiments with different user groups (e.g. kids, teens or adults). In some cases, as in the case of the presented e-auction house, it is even desired to join the execution of the virtual world application with the non-virtual environment, such as the web application or even the real world (see Section 5).

Combining several different environments and their simultaneous execution raises several inter-operability issues, such as:

1. Parallel presence, movement and interactions of avatars in different virtual worlds.
2. Virtual world participants that speak different languages try to participate in the same ‘‘single language’’ application.
3. Heterogeneous architectures of virtual worlds make it difficult to monitor and react to virtual world events and interactions, and to causally update the virtual world model according to the EI state.

Considering point (1) solving parallel avatar presence and movement is out of scope of this research. However, we demand only a basic level of virtual worlds' interoperability. This means that participants from other virtual worlds are visualized as limited avatars, which only perform institutional actions (e.g. joining a scene). Thus, for instance, it is not shown how they walk around the room. An example application using multiple virtual environments is an auction where users from Second Life, Active Worlds or PS3 Network participate in the same auction room with a fixed amount of chairs. Hence, as soon as a participant takes one of the chairs, his avatar appears sitting in a chair, in all other universes (i.e. Virtual Worlds).

The popular solution to solve the problem of multilanguage environments, mentioned in point (2), is to define a common ontology, that each of the participating virtual worlds adopts for controlling and executing world's interactions. In our approach, we rely on Electronic Institutions, which define such common ontology for all institutional interactions.

Considering heterogeneous architectures in point (3), we need a mechanism that creates a mapping between virtual world dependent actions and institutional messages. In reverse, it has to define mappings between institutional events and target virtual environments, where such an event should be visualized. Concerning the content manipulation, the virtual world model is generated prior to the execution of the Virtual Institution, and then it is dynamically updated during the execution of the institution (e.g. launching of a scene in the normative layer can add a new room to an institutional building in the visual interaction layer). In our approach, we use Virtual World Grammar, which can dynamically manipulate 3D content of multiple virtual worlds.

Bogdanovych et al. presented the architecture of a causal connection server, which was able to create a causal connection between different environments (e.g. virtual world and mobile application) (Bogdanovych et al., 2008). The drawback of this solution is a simple action-message table which makes it difficult to route events between different environments and an Electronic Institution. Therefore, we propose VIXEE as an innovative Virtual Institution eXEcution Environment which adds important extensions to previous Virtual Institution infrastructures. These extensions address generic and dynamic features. That is, VIXEE allocates at run-time participants from different VW worlds, and it modifies on the fly the content of a virtual world (e.g. a new virtual room can be added during the execution of the infrastructure). An important factor of any middleware is its agility that is its ability to respond quickly and safely to both layers event during heavy loads. Therefore, we have evaluated our solution by measuring response time with a large number of agents (up to 500 agents).

VIXEE has already been successfully deployed in an e-learning scenario, the social historical simulation of the City of Uruk 3000 BC (Bogdanovych et al., 2011; Trescak, 2012) and an e-government scenario, a virtual market of water rights called vmWater (Almajano et al., to appear, 2012a,b). We are working in another application deployed using VIXEE, it is a serious game for SmartGrid (electric grid) training (Bourazeri et al., to appear).

The rest of the paper is organized as follows. Section 2 provides background information on concepts related to this research. Section 3 discusses related work. Then, in Section 4, we present VIXEE and explain in detail its implementation. In Section 5 we present a case study of an e-auction house application, using which we evaluate our system in Section 6. Finally, in Section 7, we give conclusions and state our future work.

2. Background

The concept of combining Electronic Institutions with 3D virtual worlds was introduced in Bogdanovych et al. (2005) as Normative Virtual Worlds and named Virtual Institutions. In this context, Electronic Institutions are used to specify the rules that govern participants' behaviors, while 3D virtual worlds are used to facilitate human participation in the institution. Therefore, participants of Virtual Institutions can be both human and software agents. A Virtual Institution is separated into a *Normative Control Layer* and a *Visual Interaction Layer*. This provides support to the conceptual separation between the normative control of interactions and the design of the virtual world, i.e., the design of the 3D graphical user interface. The Normative Control Layer is responsible for the institutional control of interactions among participants, while the Visual Interaction Layer focuses on the 3D representation of the institution. Regarding participants, humans participate in the system by controlling an avatar on the Visual Interaction Layer. Software agents are directly connected to the Normative Control Layer, visualized as ‘‘special’’ avatars in the Visual Interaction Layer and participate by exchanging messages.

Both layers are causally connected, whenever one of them changes, the other one changes in order to maintain a consistent state (Maes and Nardi, 1988). In the case of our Virtual Institution, a Causal Connection Layer keeps a consistent state between the model, represented by the Normative Control Layer, and its view, represented by the Visual Interaction Layer. Fig. 1 shows an overview of the three layered architecture of Virtual Institutions.

There is an important conceptual difference between Electronic Institutions (EIs) and Virtual Institutions (VIs). In EIs everything is regulated in the sense that it is defined what is permitted, and everything else is prohibited. In VIs the situation is