Virtual Institutions: Normative Environments Facilitating Imitation Learning in Virtual Agents

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Abstract. The most popular two methods of extending the intelligence of virtual agents are explicit programming of the agents' decision making apparatus and learning agent behaviors from humans or other agents. The major obstacles of the existing approaches are making the agent understand the environment it is situated in and interpreting the actions and goals of other participants. Instead of trying to solve these problems we propose to formalize the environment in a way that these problems are minimized. The proposed solution, called Virtual Institutions, facilitates formalization of participants' interactions inside Virtual Worlds, helping the agent to interpret the actions of other participants, understand its options and determine the goals of the principal that is conducting the training of the agent. Such formalization creates facilities to express the principal's goals during training, as well as establishes a way to communicate desires of the human to the agent once the training is completed.

1 Introduction

Non-gaming Virtual Worlds like Second Life (http://secondlife.com) or Active Worlds (http://activeworlds.com) constantly grow in popularity. Their significance was highlighted by many researchers (i.e. [1], [2]). A report by *Gartner predicts that 80% of the Internet users will be actively participating in non-gaming Virtual Worlds by the end of 2011* [1].

The popularity of such Virtual Worlds creates a demand for intelligent autonomous agents operating within these virtual environments. The need for human-like sales assistants in E-Commerce environments, computer controlled teachers in virtual classrooms, or smart guides and travel agents in tourism systems stimulates researchers to look for more and more complex software architectures controlling the behavior of the autonomous agents.

The behavior of the majority of such virtual characters today is often controlled using preprogrammed scripts, finite state machines, or tree searches. None of these methods is well known for generalization capabilities. Consequently, common approaches for such virtual characters lead to ennui and frustration of the humans interacting with them. After a short period of interaction, the actions of computer-controlled characters tend to appear artificial and lack the element of surprise human participants would provide. Moreover, if a human acts in a way not envisaged by the programmers of the characters, such characters simply appear to behave “dumb” [3].

Another serious problem is making virtual agents appear believable. Carnegie-Mellon set of requirements for believable agents include personality, social role awareness, self-motivation, change, social relationships, and ”illusion of life”. Integrating these believability characteristics into virtual environments is associated with computational and architectural complexity; is platform and problem dependent, and is essentially far from achieving a high level of believability [4]. No existing virtual agent was yet able to pass the Turing test [4], adaptations of which are the only known research method of believability assessment [3].

Instead of explicitly programming various believability characteristics some researchers rely on the simulation theory. The key hypothesis behind this theory can be best summarized by the cliché “to know a man is to walk a mile in his shoes” [5]. It is assumed that simulation and imitation are the key technologies for achieving believability. In particular, using these techniques to produce more human-like behavior is quite popular in cognitive systems research [6].

Applying simulation theory to the development of autonomous agents is known as *imitation learning*. This approach is not new but it is not as popular as other types of learning and, most importantly, it has not been very well developed. Most of the imitation learning research is focused on robots intended for deployment in physical world [3]. This focus led to a situation where research aimed at behavior representation and learning struggles with issues arising from embodiment dissimilarities [7], uncontrollable environmental dynamics [8], perception and recognition problems ([6], [7]) and noisy sensors [6].

The aforementioned problems do not exist in Virtual Worlds. The sensors available there are not noisy, all participants normally share similar embodiment (in terms of avatars) and the environment is controllable and easily observable. Thus, using imitation learning for virtual agents represented as avatars within Virtual Worlds ought to be more successful than applying it to robots situated in the physical world. Despite this fact, only a few scholars have taken this direction and most of them are concerned with gaming environments, where virtual agents are used as computer controlled enemies fighting with human players [9], [10].

Focusing on video games makes possible to introduce a number of limitations and simplifications, which are not acceptable in non-gaming Virtual Worlds. The algorithms described in [9] seem to be quite successful in teaching the agent reactive behaviors, where next state an agent should switch into is predicted on the basis of the previous state and a set of environment observed parameters. These algorithms also prove to be quite useful in learning strategic behavior inside a particular video game (Quake II). The main limitation we see in this approach is that players' long term goals are assumed to be quite simple, namely to collect as many items as possible and to defeat their opponents [11].

In non-gaming Virtual Worlds, the situation is not that simple, as goals are more complex, and there is also a need to recognize the goals, desires and intentions of the human. For understanding the goals it is required to be able to assign the context to the training data and sort it into different logical clusters. Recognizing the desires and intentions is necessary when the agent is to replace the human in doing a particular task. For example, a principle may wish to train a virtual agent to participate in an auction on human's behalf. One of the reasons why such tasks cannot be achieved by the algorithms presented in [9] and [10] is that there is no mechanism provided there to communicate human requests, and there is no method for the agent to infer human's desires and intentions.

In respect to making agents understand the desires and intentions of the humans, existing approaches fall under one of the following extreme cases. First case is to purely rely on explicit communication between agents and humans, when every goal, belief, desire, intention and action the human trains the agent to perform is formalized for the agent. Another case is the fully implicit communication between humans and agents, when any explicit form of communication is considered unacceptable. As a result in the first case it often becomes easier to program the agents than to train them and in the second case only simple reactive behaviors can be learned and more complex behaviors are mostly left out (as the agent can not recognize complex human desires or intentions).

In this paper we explore the following two research hypotheses in relation to using imitation learning for virtual agents in non-gaming Virtual Worlds:

Hypothesis 1: It is impossible for the agent to implicitly recognize all the desires and intentions of the human and, therefore, a high-level communication language is required in some cases for the human to make the agent aware of those.

Hypothesis 2: For the agent to be able to handle the complexity of the human actions and goals, it should not purely rely on its own intelligence but should expect some help from the environment it is situated in.

The first hypothesis is an attempt to find a happy medium between the previously described extreme cases. In non-gaming Virtual Worlds participants' goals are not as trivial as in video games. On the one hand, always providing the agent with detailed formalization of human's actions, goals, intentions and desires is even less effective here. On the other hand, the goals and intentions of the humans are too complex for the agent to be able to infer them implicitly.

The second hypothesis is based on the suggestion made by Russel and Norvig that the agent's ability to successfully participate in some environment and extend its intelligence there is highly dependent on the complexity of this environment [12]. Authors mention that having the agent situated in a fully observable, deterministic and discrete environment significantly simplifies agent programming and valuably facilitates agent learning. As an example of a fully observable, deterministic and discrete environment, we consider Virtual Institutions, which are Virtual Worlds with normative regulation of participants' interactions. Through introducing the normative regulation of the interactions Virtual Institutions help to interpret human actions, identify logical states of the agent and let humans communicate with an agent using a high level language in situations where it is impossible for the agent to recognize humans desires and intentions.

The key message this paper is trying to communicate is that *shifting some efforts into formalizing the environment may prove being more beneficial than spending them on improving agents' intelligence*. To support this message we show how the application of Normative Multiagent Systems can help in formalizing the interactions of humans and agents participating in a Virtual World.

The remainder of the paper is structured as follows. Section 2 provides a description of the Virtual Institutions concept. In Section 3 it is shown how using Virtual Institutions can facilitate imitation learning in virtual agents. Finally, Section 4 summarizes the contribution and outlines the directions of future work.

2 Virtual Institutions as Normative Virtual Worlds that Enable Learning from the Behavior of the Inhabitants

We consider Virtual Institutions [13] being a new class of normative Virtual Worlds, that combine the strengths of 3D Virtual Worlds and Normative Multiagent Systems, in particular, Electronic Institutions [14]. In this "symbiosis" the 3D Virtual World component spans the space for visual and audio presence, and the electronic institution component takes care of enabling the formal rules of interactions among participants. The normative system of the Virtual Institutions provides context and background knowledge for learning, helping to explain the tactical behavior and goals of the humans. The 3D representation provides the necessary environment to observe the behaviour of the humans. It assumes similar embodiment for all participants, including humans and autonomous agents, so every action that a human performs can be observed and, if necessary, reproduced by an autonomous agent.

One of the initial stages in the development of Virtual Institutions is formal specification of institutional rules. The specification defines which actions require institutional verification, assuming that the rest are safe and can be instantly performed. On the one hand, the specification plays the key role in the environment formalization and eventually helps the agent to put its actions into context. On the other hand, due to its formal nature and the available formal verification mechanisms, rules specification is a powerful way to ensure the validity of the participants' interactions and provide guarantees of correct rule enforcement. The specification is expressed through three types of conventions and their corresponding dimensions (for detailed explanation see [14]):

Conventions on language form the *Dialogical Framework* dimension. It determines language ontology and illocutionary particles that agents should use, roles they can play and the relationships or incompatibilities among the roles.

Conventions on activities form the *Performative Structure* dimension. It establishes the different interations agents can engage in, and the role flow policy among them. Each interaction protocol is specified in the so-called scenes, which define the possible interactions agents may have.

Conventions on behaviour form the *Norms* dimension. It captures the consequences of agents' actions within the institution. Such consequences are modeled as commitments (obligations) that agents acquire as consequence of some performed actions and that they must fulfill later on.

A virtual institution is enabled by a three-layered architecture presented by three conceptually (and technologically) independent layers, as shown in Fig 1.

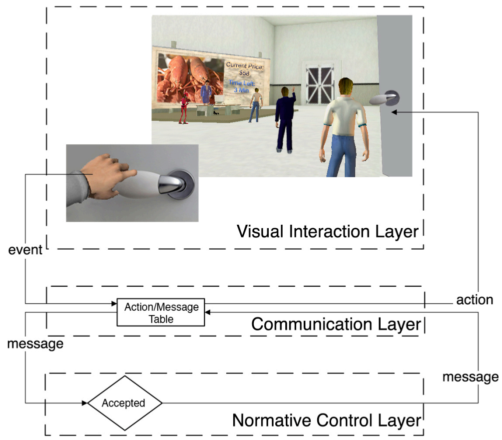

Fig. 1. The operation of the three-layered architecture of the virtual institution.

Normative Control Layer. Its task is to regulate the interactions between participants by enforcing the institutional rules.
Communication Layer. It causally connects the above discussed institutional dimensions with the virtual world. It transforms the actions of the virtual world into messages, understandable by the institutional infrastructure and vice versa, using the Action/Message table created by the system designers.
Visual Interaction Layer supports the immersive interaction space of a virtual institution. Technologically, this layer includes a 3D virtual world and the interface that converts communication messages from the Communication Layer.

Fig 1 outlines the interaction between all these layers on an example of the agent requesting to enter a room inside the Virtual World. The human moves the mouse pointer over the door handle and clicks the mouse button (requesting the avatar in the Virtual World to open a door by pushing it handle). With the help of the Action/Message table this event is then translated into a message understandable by the Normative Control Layer. In case such a message is accepted in the Normative Control Layer the response message is sent back to the Communication Layer. The Communication Layer again consults the Action/Message table and transforms this response into the corresponding action which is executed in the Visual Interaction Layer. In the given example this action will result in opening the door and moving the avatar through it.

3 Enabling Imitation Learning with Virtual Institutions

An important feature of Virtual Institutions is that every human participant (principal) is always supplied with a corresponding software agent. The *couple agent/principal* is represented by an avatar. Each avatar is controlled by either a human or the autonomous agent. The agent is always active, and when the human is driving the avatar and acts in the Virtual World, the agent observes those actions. This allows the deployment of learning algorithms in order for the agent to learn how to make the decisions on behalf of the human.

The formal specification of a Virtual Institution contributes to learning the human-like behavior through providing the autonomous agents with a way of translating the actions performed by the human into the formal context of the institution. The dimensions of the institutional specification contribute to the quality of learning in the following way:

- *Dialogical Framework*: the roles of the agents enable the separation of the actions of the human into different logical patterns. The message types specified in the ontology help to create a connection between the objects present in the Virtual Worlds, their behaviors and the actions executed by the avatars.
- *Performative Structure*: Enables grouping of human behavior patterns into actions relevant for each room.
- *Scene Protocols*: Enable the creation of logical landmarks within human action patterns in every room.

Fig. 2 illustrates how the institutional specification influences the imitation learning of autonomous agents in Virtual Institutions.

Fig. 2 a) outlines a performative structure of a prototypical Virtual Institution containing three rooms (registrationRoom, meetingRoom and tradeRoom). In the performative structure graph these rooms are connected through transitions (corridors). The arcs in the graph (visualized as doors) are marked with the permissions of the agents playing particular roles to enter certain rooms or corridors. Each of the rooms is associated with its interaction protocol. To determine the entrance into the institution and its exit, invisible rooms “root” and “exit” are included into every Performative Structure.

A protocol of each scene is specified by a finite state machine establishing the possible interactions agents may have. Fig. 2 b) shows the specification of the registrationRoom scene. The upper part is the scene protocol, while the lower part outlines the institutional level messages that can change the scene state.

Fig. 2 c) illustrates how the institutional specification can be used to simplify the imitation learning of virtual agents. It represents agent’s decision graph created with the help of the institutional specification.

The decision graph is created and modified while the principal is acting in the Virtual Institution. These actions can be of two types. The actions that require institutional verification are the institutional level actions, while the rest are the actions of the visual level. The training of the virtual agents for believable behavior in Virtual Institutions happens on both visual and institutional levels. The actions of the visual level are important for capturing, for example, human-like control of avatar movement. The actions of the institutional level, on the one hand, allow the autonomous agent to make decisions about when to start and stop collecting data about the actions of the visual level and which context to assign to the collected sequences. Analyzing the sequence of institutional level actions on its own allows to understand how to reach different rooms and separate the sequences of actions there into meaningful logical states of the agent.

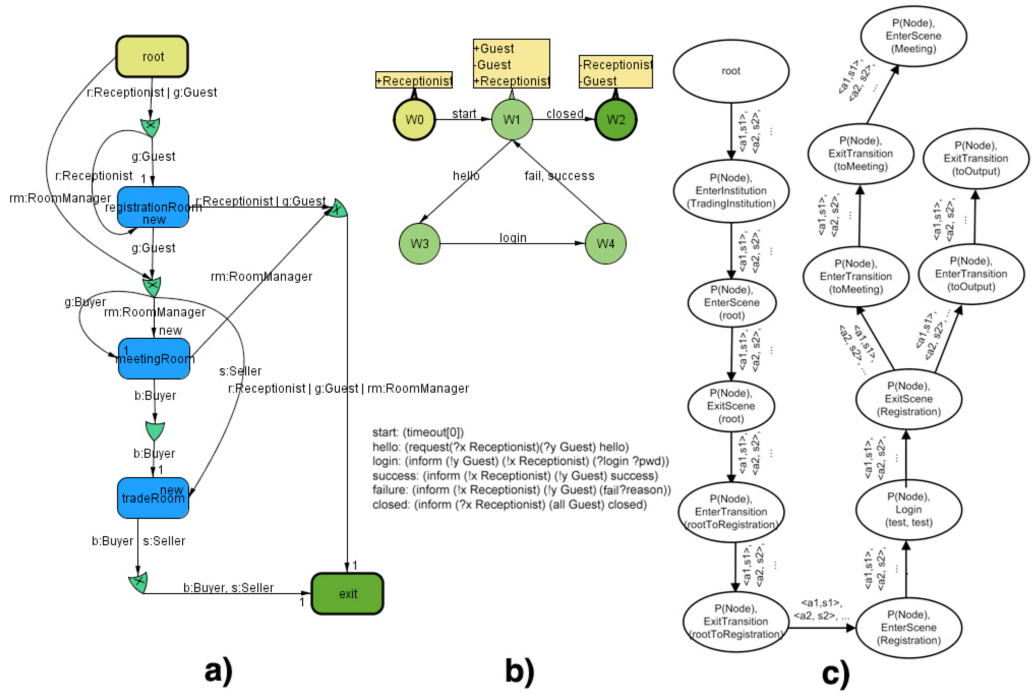

Fig. 2. Institutional Specification and Agent Training.

Through the three-layered architecture presented in Fig. 1 each institutional level action is transformed into an institutional message. The nodes of the agent's decision graph correspond to these institutional messages. Each of the nodes is associated with two variables: the message name and the probability of this message to be executed. The arcs connecting the nodes are associated with a set of parameters the avatar in question was able to sense in the environment and the recorded sequences of the visual level actions that represent believable avatar transitions between the institutional level actions.

In order to communicate human's desires to the agent we have defined a list of textual commands. Each command starts with the special keyword "Do:" and the rest of the command is an institutional message. When the agent receives such an instruction it searches its current decision graph for the node with the corresponding institutional message, and backtracks through it to the current node. Hence, it executes the sequence of the most probable actions (with the highest probability) that lead from the current node to the target node. More details about the learning algorithm can be found in [13].

4 Conclusions and Future Work

We have presented the concept of Virtual Institutions as the facilitator of imitation learning and a mechanism of high level communication of human desires to a virtual agent. Future work includes applying Virtual Institutions to the domain of electronic markets, using the described learning mechanisms within this domain and conducting experiments on the evaluation of believability.

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