Modeling Behavior of Virtual Actors:

A Limited Turing Test for Social-Emotional Intelligence

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***Abstract*—This work presents the design, implementation and study of (1) a videogame-like virtual environment simulator, enabling social interaction of avatars controlled by human participants and by virtual actors; (2) a set of virtual actors with varying forms and degree of social-emotional intelligence, based on the eBICA cognitive architecture; and (3) a limited Turing test for social-emotional intelligence, involving human participants and virtual actors. The virtual environment simulator allows for various forms of emotionally-laden interaction of actors immersed in it in the form of avatars, with data collection characterizing their behavior in detail. The objective here is to compare and evaluate models of social-emotional reasoning based on the Turing test results and other objective behavioral measures, also taking into account subjective judgment of participants. One of the long-term goals is achieving human-level believability of socially-emotional virtual actors, such as non-player characters in games, personal assistants, robots, and other intelligent artifacts. Preliminary results indicate importance of social-emotional intelligence for believability, and support assumptions of the eBICA architecture.**

Keywords—cognitive modeling; virtual actor; virtual environment.

I. Introduction

Over the past decade, a lot of progress has been made in creation of complex virtual environments. Among the outstanding representative examples are a variety of three-dimensional computer games. With each step of the development of technologies to create such environments the developers encounter new challenges to create believable virtual actors controlled by complex systems of artificial intelligence. There are two major problems in this respect that can be identified: the credibility of the virtual actors and the efficiency of their behavior, for example, the degree of similarity of their actions to human action and the high efficiency in achieving their own objectives. In this paper, we focus on one aspect of the creation of virtual environments and virtual actors, which relates to the credibility and efficiency of virtual actors.

Since the modern re-emergence of ideas about thinking machine [9], the main task in the field of artificial intelligence can be considered as the creation of a general-purpose reasoning mind to be somewhat similar to that of humans. Modern researchers are developing more and more new ways to achieve this objective. Very important here are useful tests and evaluation criteria, that may allow one to refute a theory that is not worthy of the efforts of developers [10,11].

One of the main human cognitive capacities is emotionality and emotional intelligence, particularly, emotional reasoning, decision making and behavior control. Human emotions present a vast area for scientific study, including experimental and theoretical challenges. Recently, many studies were aimed to develop an understanding of basic relationships and patterns characterizing human emotions [12,13]. At the same time, the main practical interest originates from the need for so-called "simulation" of emotions, including their internal processing in artifacts.

Integration of the variety of disparate theoretical and modeling approaches [1-5] to understanding the nature of human emotional intelligence becomes a key challenge in artificial intelligence. A grand-unifying theory of emotional cognition seems to be around the corner.

Creating intelligent agents that are capable of effectively and efficiently functioning in a real social environment, including learning and adapting to it, is a task that would be impossible to solve without understanding and using mechanisms of social emotional cognition. Therefore, the present work addresses such mechanisms and principles of their realization in an agent in the context of a social emotional challenge in a virtual environment, as presented below.

II. Materials and Methods

A. Virtual Environment Simulator

The starting point in designing a virtual actor is always related to selection or creation of an appropriate virtual environment. While some researchers aim to create a specialized environment for their experiment, many use existing ones. By using publicly available virtual environments, researchers can focus on developing the artificial intelligence and avoid criticism for carelessness and inability to scale developments in the area. The popularity of many virtual environments is primarily due to the richness of their components and interface capabilities, the quality of documentation, general accessibility and prevalence within the developer community.

During the study of various practical virtual environments at the beginning of this work, we found that each of them can be used as a means for cognitive modeling. With varying degree of difficulty, one can build a customized virtual environment for a specific cognitive modeling task, such as the study of virtual actors, based on virtually any popular virtual environment.

The problem is that most publicly available virtual environment simulators are proprietary systems developed for third parties. Thus, not every such system may be used for a given task of cognitive modeling, without violating the intellectual property rights. It is worth noting, however, that most developers offer special systems for the development of user scenarios and environments, strongly encouraging the creativity of third-party developers.

On the basis of this preliminary analysis, we concluded that the most practical way to address the problem of cognitive modeling is to develop our own virtual environment, where we would have full control of the environment, and the behavior of the various entities in it, including virtual actors. The appropriate for our purposes virtual environment should have a high degree of complexity of visualization, including video and audio interfaces, that are not available in most commonly used simulators.

In addition to the enhanced visual component of the developed setup, we also found it necessary to implement special functionality in our virtual environment, e.g., allowing us to profile virtual actor's performance using the data collected during the experiment, to test the network availability during the actor's remote interaction, and to simultaneously conduct multiple experiments.

1) Settings and Procedure

In this study, we decided to develop an application for the cognitive modelling study in the form of a virtual *Experimental Stand*, enabling interactions of virtual and human actors with each other in one developing scenario.

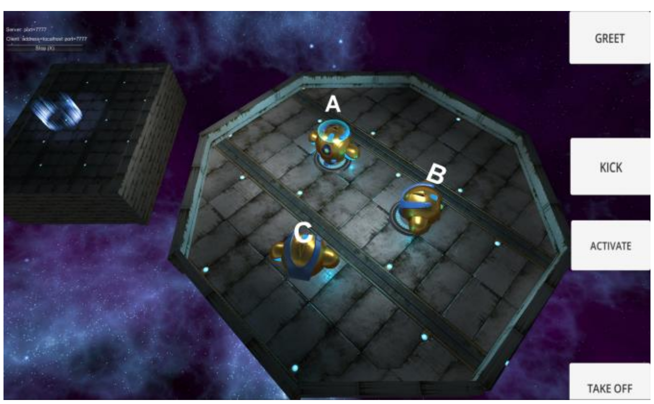

Figure 1. Screenshot of the working virtual environment with three actors in it (avatars A, B, C). Teleporter terminals located in the middle of the platform are shown by blue circles on the floor and are currently occupied by actors A and B. The terminal of A is activated, which is indicated by a blue circle above A. Buttons on the right represent actions available to A.

The experimental setup consists of a virtual stage, in which three avatars are allocated (Figure 1). Each avatar can be controlled by a human player or a virtual actor. The virtual stage consists of two parts: a rescue zone (further referred to as "the tower": the left component in Figure 1) and an action zone (further referred to as "the platform": the right component in Figure 1). The platform has two teleported terminals (Figure 1). Actors can be moved from the platform to the tower by means of teleportation, as described below. The experiment is conducted as a sequence of logically identical epochs, or rounds. Each round has a fixed limited duration, and may terminate earlier, if certain conditions are met. Following the termination, a new round starts automatically. Below we briefly describe the rules of this game.

Initially, all actors are placed on the platform at random locations. Each actor located on the platform has the following available behaviors.

- Greet another actor (always available). Greeting is accompanied by a voice message and a predefined move of the avatar, turning toward the target of greeting.
- Kick another actor (available at a short distance; also accompanied by a sound). The kicked actor flies a large distance in the direction of the kick.
- Activate another teleporter (available from a teleporter only; cannot activate own teleporter). This action puts the other teleport in the active state, enabling teleportation.
- De-activate another teleporter (available from a teleporter only; cannot de-activate own teleporter). This action puts the other teleport in the inactive state, disabling teleportation.
- Take off: make your own teleportation (available from an active teleport only). Own teleportation is possible from an active teleporter only. This action moves the actor from the platform to the tower.

The action of greeting is also available to actors located on the tower. In addition, an actor located on the tower may perform the following two actions, each of which leads to the termination of the round:

- Save a selected actor located on the platform. This action transfers the selected actor from the platform to the tower.
- Escape alone. This action allows the only player located on the tower to complete the round.

The round terminates automatically whenever two actors reach the tower, or an actor on the tower escapes alone, or the time limit expires. Upon termination, all actors located on the tower win, others lose.

2) Implementation

During the development of Experimental Stand, the general architecture shown in Figure 2 was designed and used for implementation. The system requires a server for enabling multi-user interaction, allowing us to perform the experiment with a number of human participants.

The server module must meet certain requirements in terms of reliability, responsiveness and continuous availability. The advantage of using a dedicated server is in the ease of connectivity as well as in the independence of the experiment from participants' physical location.

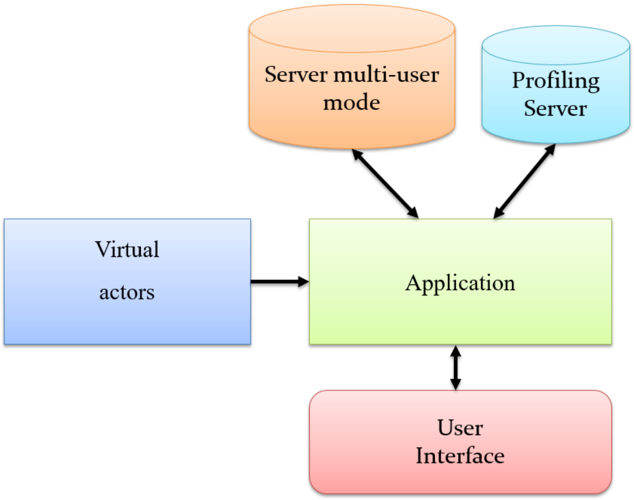

Figure 2. General architecture of the implemented Experimental Stand, showing interactions between its modules. The core component, labeled Application, implements the virtual environment. Components can be distributed among several computers connected to the broadband Internet.

Virtual actors are connected to the application via a specially designed interface. The interface allows one to connect to virtual actors that are implemented independently, each based on its own model or cognitive architecture. The advantage of this system can be explained as the opportunity to alter any virtual actor through a simple modification of the application.

Modular connections of individual virtual actors are made possible due to the complete replacement of the standard approach, which is based on creating one large complicated volume of the code. The model that we use suggests a much simpler programming approach, based on limited interactions between the developer of the virtual environment and designers of virtual actors. The latter only need to design a behavioral model of the virtual actor and put it in a given pseudocode template. This approach allows us to facilitate the integration of virtual actors as well as to accelerate their implementation.

B. Virtual Actor

In the context of the present work, it is important to understand that our artificial intelligence used to control a virtual actor should not only replace a human player, but also needs to imitate human behavior. In particular, this feature is very important for computer game development. For example, when one plays chess with a computer, one assumes that it is possible to play as with a real person, despite that the opponent is an artificial intelligence. Sophisticated computer games presuppose the existence of high-quality artificial intelligence systems that are able to manipulate objects following plausible scenarios. The human players are the ultimate judges who primarily determine the success of any given artificial intelligence approach in computer games. Therefore, the main factor determining the success of artificial intelligence is satisfiability of the needs of the majority, not the ability to beat the human in the game.

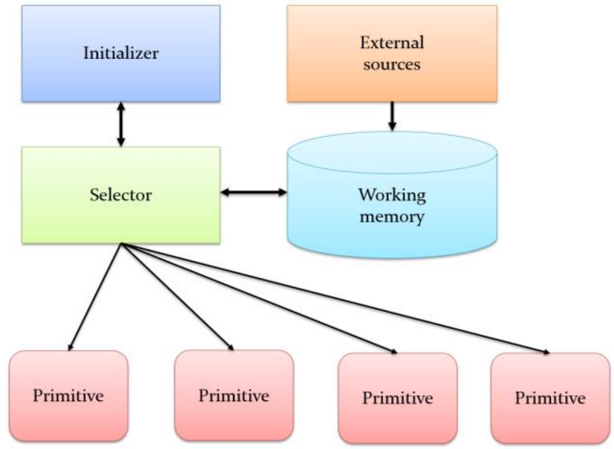

Figure 3. General architecture underlying the implementation of a virtual actor. The cognitive architecture eBICA [6] defines the behavior model implemented using these components.

During the onset of research in virtual actor's theory and cognitive architectures used in games, a general architecture of a non-player character was designed (Figure 3). In our implementation, it works as follows.

At the beginning of each round, variables in working memory are initialized, such as search results and representations of objects in the environment. Each actor has a working memory, in which all cognitive events take place, reflecting events that happen in the virtual environment. Real-time evaluations of variables are transmitted to the actors. Using these data, virtual actors perform their cognitive and behavioral operations, based on a selected cognitive architecture with probabilistic decision making. These operations are realized as basic behaviors described in the previous section, using the following primitives.

- *Primitive of a kick*. It consists of a sequence of motion for the player who wants to strike an opponent at the distance at which this action is possible.
- *Primitive of own teleportation*. An actor may decide on the implementation of this primitive, only if the teleport is enabled. When the teleport will be shut down after the actor begins its movement toward the teleporter, then the actor will stop and switch to the selection of other actions.
- *Primitive of teleporter activation*. It consists of a sequence of moves toward the teleporter and an activation delay, that simulates reaction time of a human player who uses the teleporter. After this delay, an activation takes place.
- *Primitive of protecting the teleport*. It consists of a sequence of actions: movements toward the teleporter, waiting at the teleporter, removal of an adversary player from the teleporter at the specified

time using a kick, and/or returning to the teleporter after being kicked to a certain distance from it.

The memory of all actions committed by self and by other players is preserved in a virtual actor from one round to another. This allows us to form lasting relationships between actors over a sequence of rounds.

The rules determining how to perform the selection of actions based on the appraisal of actions committed by players with respect to the actor and other players are determined by the eBICA cognitive architecture, introduced by Samsonovich [6]. Table 1 summarizes the appraisals used for the actions in this virtual environment. Equations (1)-(3) define the laws of model dynamics determining the behavior of a virtual actor.

Probabilities of the choices are determined by appraisals of the actions that take values on the two-dimensional semantic map, with the two dimensions interpreted as "Valence" and "Dominance". Coordinates of the 6 actions are determined by the coordinates of the action name on the semantic map [6]. Normalized initial values of the coordinates were taken from the semantic map [8].

These values for the action primitives have been further adjusted empirically, as a result of the knowledge of what action has a larger contribution to the gameplay, as well as by taking into account the polysemy of the names of actions.

TABLE I. AFFECTIVE VALUES OF BEHAVIORAL PRIMITIVES

Action	***Valence***	***Dominance***
Greet	0.93	0.15
Kick	0.26	1.07
Activate	1.10	0.20
Defense	0.11	1.20
Save	1.80	0.15
Escape	-1.83	-0.37

Dynamical equations used here to update the appraisals values are:

$$A_{target}^{t+1} = (1-r)A_{target}^{t} + rA_{action} \quad (1)$$

$$A_{actor}^{t+1} = (1-r)A_{actor}^{t} + rA_{action}^{*} \quad (2)$$

Here *t* is the moment of discrete time, and *r* is a small positive number (a model parameter that was set to 0.01). The likelihood *L* of a specific action is proportional to

$$L_{action} = [Re\big(A_{action}\times(A_{actor}^{*} + A_{target}\big)]_{+} \quad (3)$$

Here $[x]_+$ is equal to the positive values of *x* and is zero otherwise, A^* is the complex conjugate of *A*. Intuitively, this formula means that the action is more likely to be selected, when its appraisal matches the appraisal of the actor and also matches the appraisal of the target, in which the dominance component is inverted.

C. *Experimental Paradigm*

The experimental paradigm used here is based on the random interaction paradigm described in [6] and on the paradigm of the “Russian elevator story” [7]. The scenario used here is essentially a modified Russian elevator story scenario, however, in the present work, the action takes place in space, on the platform, as described above in Section II.

Three agents are confined on the platform, but are free to move around it. They may greet each other, hit each other, move from place to place, activate a teleporter, use already activated teleporter to move to the safe zone (the tower). When using an activated teleporter, the avatar moves from the platform to the tower. There it has opportunities to save one of the other players or to escape alone. Each round is limited in time to one minute. The maximal number of freed actors is two. The minimal number is zero. The goal of the game is to escape to the tower.

The aim of this study is to compare two approaches in modeling of virtual actors, as well as to find patterns in emergent social-emotional relationships among the actors, understood in our case as mutual appraisals of the actors. These appraisals are evaluated using the collection of actors’ interaction data in the virtual environment. Therefore, the definition of appraisal is also given by the cognitive architecture and its parameters, used to implement virtual actors.

Thus, the general paradigm is based on a group of three agents interacting with each other, using 6 possible actions. The interacting actors and their actions are appraised by the virtual agents identically, because they all receive identical information and use identical internal cognitive models.

D. *Data acquisition and analysis*

The profiling Server was used to store all the necessary information about behavior of actors. In the experiment, actors can perform actions of various nature. To obtain reliable results, one needs to use large volumes of information. In our experiment, data recording occurs in real time. The server is used primarily for centralized data collection with different types of devices that allows one to receive large amounts of data for statistical processing, without the need for time consuming operations to retrieve data from each of the user devices. This method does not introduce any delay in execution of the application.

In the future, on the basis of these data, as well as the comments of the subjects we will produce improvements or complete revision of the existing prototype, in order to improve performance.

E. *Subjects and Procedure*

A total of 8 students participated in the study. One hundred percent of the students were male, and 100% reported that Russian is their native language. The ethnic breakdown was as follows: 100% White. A total of 37.5% of the students were from Moscow while others reported that they were from different parts of Russia. In terms of their student status, they are students of the 4th year MEPhI. All of the students were full time students. All of the students had graduated from public high schools.

The experiment was conducted on 4 subject pairs that were randomly created from the participating students. Each experiment lasted for one hour. The first half hour players interacted with a control virtual actor lacking any social-emotional intelligence. The remaining half hour players interacted with a virtual actor that possessed elements of social-emotional intelligence. The experiment was carried out using the Experimental Stand implemented in the form of a cross-platform application, which makes experiments easily reproducible. The experimental application was preinstalled on three different devices. Two of them were used by the subjects and the third was used by the experimenter. At any time when the test was running, the experimenter was able to observe the session.

The subjects participated in the experiment using similar devices placed in different rooms. They were isolated from each other and had no means of communication between them. Instructions and information about the game were given to participants before the experiment. Each of the subjects was asked to determine and report, upon reacing confidence in the judgment, which one of the avatars is controlled by the virtual actor, and which one by a human player. Subjects reported their judgments by indicating the ID of the player that was controlled, by their opinion, by a virtual actor, as well as the time of the decision. After the experiment, the subjects were asked to name the reasons due to which they have made their judgments.

Analysis of the results of the experiment included comparison of time intervals required for the subjects to make their judgments.

It was evaluated time intervals, for which the players make a statement, as well as allegiance to this statement. This way it was produced a similar test as a limited Turing test.

III. Results and Analysis

Based on the outcomes of this experiment, we can conclude that elements of social emotional intelligence have a signigficant impact on the similarity of behavior of a virtual actor and a human player. In addition, most common comments on the characteristics of virtual actor behavior are:

- Actions of the virtual actor are too logical.
- A virtual actor can be analyzed, allowing one to predict its behavioral patterns.
- Sometimes there are errors in the behavior of the virtual actor, giving it an indication of its unnaturalness.
- Virtual actor is too deterministic in its actions.
- Virtual actor does not participate in the "game within the game". Sometimes participants start playing a game within the game by the rules that they spontaneously select, and when this happens, the virtual actor cannot understand the anomalous behavior of these players.
- There were several errors noticed in behavior of virtual actors (e.g., it was observed that the virtual actor can teleport a player from the tower).
- Dealing with problems associated with attempts to experimentally connect with the Internet using an unstable connection.

Since during experiments we carried profiling of all players using all available data, it was possible to make analysis of the records in order to detect new patterns and primitives and to calculate the human response time as a reaction to external actions with respect to both, the actor - and other.

Taken together, the conducted Turing test experiments on 8 subjects (8 + 8 sessions) with virtual actors, a statistically significant difference in the frequency of correct and incorrect answers to the main question of the test (which of the two avatars is controlled by a machine) was not found. This applies to both the virtual actors having elements of social and emotional intelligence, and the traditional “heartlessly rational” virtual actors. However, comparison of the time required for the subjects to answer the question of the test, revealed that this time interval was significantly greater ($P < 0.042$) in the case where an avatar controlled by a virtual actor, having elements of social and emotional intelligence. This is the first positive result allows us to hope that the correct approach to solving global problem.

IV. Discussion

A. Summary, interpretation and implications of the outcome

Virtual environment with the ability to dive into it the virtual actors of various types have been developed in the course of this work. This virtual environment is cross-platform and have a multiplayer mode. In this virtual environment, a special interface to connect different models based on cognitive architectures was developed. Also, a virtual actor with social features of emotional intelligence was implemented as an example. According to the results of experiments, it was confirmed that a significant difference exists between this type of actor and the type based on a probabilistic approach (lacking emotional intelligence). The data collected during a series of experiments have a big value to researchers of virtual actors. These data allow us to appraise the interaction between virtual actors and humans. This virtual environment is a universal platform for the study of various models of cognitive architectures in a given scenario. A significant difference between emotional and social model, and model-based probabilistic approach is a step towards more and more perfect models.

B. Future work

Our future plans include improvement of the virtual environment. During the development of the virtual actor, we found the need to optimize virtual actor’s connection interfaces. When modifying the interface, it would be necessary to change the scenario and logic of the virtual environment accordingly. Future plans also include adding new situations and opportunities for the subjects, as well as comparison of virtual actor models to each other.

Our long-term goals include achieving human-level believability of socially-emotional virtual actors. Here we primarily imply non-player characters in games, personal assistants, robots, and other intelligent artifacts.

C. Conclusions

As a result of the work we can say that the designed virtual environment is far from perfect. It is worth noting that the main objectives of this work have been reached. First of all, we were able to connect the virtual actor with social emotional intelligence, which has shown its worthiness as a result of series of experiments.

Acknowledgment

This work was supported by the RSF Grant # 15-11-30014. Authors are particularly grateful to Dr. Alexei V. Samsonovich, Professor and Scientific Head of the Institute for Cyber Intelligence Systems (ICIS) of National Research Nuclear University "Moscow Engineering Physics Institute" (MEPhI).

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