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<tr>
<td><strong>Publication date</strong></td>
<td>2005-10-17</td>
</tr>
<tr>
<td><strong>Conference details</strong></td>
<td>18th Annual Conference on Computer Animation and Social Agents (CASA 2005), Hong Kong, China, October 17-25, 2005</td>
</tr>
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<td><strong>Item record/more information</strong></td>
<td><a href="http://hdl.handle.net/10197/4536">http://hdl.handle.net/10197/4536</a></td>
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NeXuS: Behavioural Realism in Mixed Reality Scenarios through Virtual Sensing

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Abstract
This paper aims to demonstrate how behavioural realism can be achieved by situating intentional agents within an Augmented Reality (AR) framework. We contest that imbuing agents with the ability to virtually sense the world within which they are situated produces a heightened sense of behavioural realism. We introduce the reader to NeXuS, a framework for the development of AR applications that depends upon these concepts to create a rich interactive environment whereby traditional boundaries between the virtual and physical domain may be overcome.

Keywords: augmented reality, computer animation, multi-agent systems

1 Introduction
NeXuS aims to create a distributed AR framework that capitalises upon the properties of intentional agents to create a single world in which people can interact with purely virtual entities in their own space. In order to reach this goal it is necessary for the embodied agents in the world to exhibit realistic behaviour. The goal of NeXuS is such that a real world user interacting in an AR environment must be able to suspend their disbelief towards a virtual avatar. This goal becomes unattainable if an avatar does not properly perceive the user’s presence. Achieving behavioural realism is the motivation behind NeXuS embedded agents. This approach inevitably leads us to examining the traditional views of separation of body and mind. These concepts were first introduced by Descartes [1] who argued for such a separation. The mental corporeal divide has been considerably debated in the field of Artificial Intelligence (AI) and robotics over recent decades but due to research such as that performed by Brooks [2] it has become generally accepted that embodiment is key to the development of AI. To achieve a goal of behavioural realism for our Avatars, we assert that we must give them virtual senses to be able to perceive the real world around them.

We shall firstly discuss this work within the broader research landscape. This will be followed by a resulting architecture to achieve the NeXuS system. Finally to show how these virtual senses can create behavioural realism, we will explore three experimental scenarios.

2 Related Work
Mixed Reality (MR) is defined by Milgram et al. in terms of a Reality-Virtuality Continuum [3] whereby environments that are either purely physical or totally virtual form opposite extrema. Between these two end-points lies the domain of mixed reality which itself can be sub-categorised into areas of Augmented Reality and Virtuality. Recent developments in AR have begun to offer a unique and intriguing method of interaction with both virtual and real artefacts [4].

A historical disconnect can be witnessed be-
between the visual state of avatars or visual containers and the cognitive processes that drive their behaviour. Much work to date has emphasised visual realism [5] as a means of bridging this disconnect. An alternative approach to addressing this issue is to endow avatars with a behaviourally realistic mental state. An increasing body of work has started to adopt this alternate approach by deploying agent based technology within a virtual domain. The MagiCster project [6], Agent Chameleons [7] and the CARTE project’s BCBM (Believable Communicative Behavior Middleware) [8] all demonstrate how an animated agent can improve and enrich human-computer interactions. These works reflect the claims of Vinayagamoorthy [9] that an emotional state is a major factor in achieving behavioural realism in avatars. Vinayagamoorthy defines emotion as ‘the cumulative result of events and knowledge’ and further states that ‘emotions are fluctuated and related to events’. One can draw parallels between the intentional state model of BDI (Belief, Desire and Intention) agents [10] and this definition of ‘emotion’.

3 Architecture

The NeXuS architecture (Figure 2) facilitates the design and delivery of experiments and experiences that fuse physical and virtual spaces into a coherent singular AR environment employing agent based technologies. A stratified architecture allows for flexibility in modifying pre-installed components or indeed adding new components to enhance the system. This section of the paper discusses each layer of this architecture, starting with the base agent platform layer and incrementally progressing to the uppermost representations of the world state.

3.1 Agent Factory Layer

The agent platform lies at the bottom level of the architecture. The platform used by NeXuS is that of Agent Factory [11], developed at University College Dublin (UCD). The Agent Factory platform is implemented in Java and offers graphical tools for the development and execution of BDI agents. Beliefs, desires and intentions are represented in Agent Factory as a corresponding collection of beliefs, commitment rules and commitments.

3.2 Agent Layer

The intelligent software agents layer exists at the centre of the NeXuS architecture. Figure 1 displays a high level representation of the major mental components of a typical agent within NeXuS. The agent’s perceptors constantly check the state of the world for any relevant changes. If any such changes do occur the relevant perceptor modifies the belief state of the agent. The role of an actuator is to enact appropriate modifications upon the agent’s environmental model whenever the belief state of the agent corresponds to a predefined inference rule.

3.3 World Layer

The upper most layer of the system architecture is the world layer itself. This layer is subdivided into two domains, the physical and the virtual. The physical domain corresponds to the hardware input/output (I/O) system components including the microphone, the display and the camera. The virtual domain encapsulates the software used to process the I/O data.

3.3.1 Virtual Domain

The world that is presented to the user is created with Sun Microsystems Java3D API. The use of Java 3D increases the simplicity of integration with the java-based Agent Factory agents. This increases overall system flexibility when compared to the more traditional usage of VRML.

Figure 1: A high level view of the Mr. Potato Head agent’s mental components
Figure 2: NeXuS system architecture

and dynamic update via the External Authoring Interface (EAI). The embodied agents’ avatars that inhabit the 3D world either as 3D Studio Max or Milkshape 3D models. Each of these models may also have a set of additional components that can be interchanged to better express the internalised beliefs of the agent that underpins their behaviour. This set of components is specified in an XML file that is parsed into the system at runtime.

The ARToolKit [12] is used by NeXuS to support both video input and the tracking of events in the physical world. The open-source jARToolKit [13] java binding was used to enable the integration of the C based ARToolKit with Java3D.

NeXuS facilitates the use of two separate speech recognition software packages for any potential vocal interaction. Originally NeXuS was designed to receive input from IBM’s proprietary ViaVoice software but recent work has integrated support for Carnegie Mellon University’s open-source Sphinx-4.

3.3.2 Physical Domain

The Physical World Layer contains the real world (I/O) components of the system with which the user directly interfaces. This layer represents the non-virtual elements of the AR environment in which the agents are embodied. The principle input technologies within this domain are the camera and the microphone. Visual output can be achieved on monitor, head mounted display (HMD) and projector. Using the HMD in conjunction with a camera placed on top of it allows for ‘Video-See-Through’ AR experience.

We now will consider how these sensory modalities can empower behavioural realism within our avatars. Specifically we illustrate this through the following three experimental scenarios.

4 Experimental Scenarios

4.1 The Flashlight Scenario

The first of these three NeXuS scenarios involves an avatar of a teen deliberatively deciding to dodge the Virtual glare of a Virtual flashlight. The purpose of this experiment (illustrated in Figure 3) is to demonstrate how BDI agents can perform deliberative actions based upon their current mental state.

It is desired to show the teen agent avoiding the light in a logical, behaviourally realistic manner. The teen agent achieves this type of behaviour by processing information on both its own position relative to the flash light and vice versa.

If a virtual wall is added to the world the teen agent’s deductive processes will result in its...
avatar positioning itself behind the wall and out of the light’s range. The effect of this addition shows the power that lies behind the use of giving agents virtual senses. The agent can react quickly to new changes within its environment and deduce out future interactions using its set of commitment rules.

Next we examine how giving these new virtual senses can be used to achieve behavioural realism within a scenario where agents are moderating interaction between two users playing a shoot and dodge style game which we call the ‘Axe Game’.

### 4.2 The ‘Axe Game’ Scenario

This second NeXuS experimental scenario demonstrates how BDI agents may be used to mediate interaction between the physical world and the virtual avatars. These agents have the ability to pro-actively respond to dynamic alterations of their belief states triggered by changes in both the physical and virtual domains of the augmented reality environment.

The axe game is a simple ‘shoot and dodge’ scenario visually played out between a Mr. Potato Head agent and a teen agent. Both agents require human input in order to fully engage in the scenario. For Mr. Potato Head this takes the form of vocal commands issued through a microphone while the teen obtains input by way of a computer keyboard. Each agent is aware of the current state of the game through both its own belief state and a score module that is constantly maintained and updated by a score actuator and a score perceptor.

The Mr. Potato Head agent has the ability to visually express its mental state by changing its 3D avatar components. This corresponds with the interchangeable facial components of the ‘real life’ Mr. Potato Head toy and is symbolic of the overall modular nature of the NeXuS framework. The facial expressions displayed by the Mr. Potato Head model reflect the current state of the axe game. Depending on whether it is winning, losing or in a tied position, the avatar will respectively appear to be happy, sad or neutral. Supplementary to this functionality, Mr. Potato Head’s eyes move left or right to a position that indicates where the teen is located in its field of vision. These simple optical cues are directly generated from the Mr. Potato Head agent’s internal deliberative beliefs. It is through this visual representation of Mr. Potato Head’s mental processes that a human user is able to gain insight into the current state of gameplay without explicitly viewing the belief states of a given agent.

The agents’ virtual senses allow for an ability to moderate interaction as they can be made aware in real time about the interactions taking place. Since both agents are given a module for...
keeping score along with corresponding actuator and perceptor they can reason about the game (see Figure 1). The agents are able to understand which user is winning thus combing this sense of reason and the virtual senses in their possession. They can be given the task to moderating interaction between users while maintaining the behavioural realism of the interaction.

4.3 ‘Dancing’ Scenario

The final experimental scenario involves two embodied agents performing a collaborative dance. The mental states of the agents are designed to detect and avoid obstacles that their avatars may encounter over the course of the dance. Figure 4 illustrates the two embodied agents and the wall that acts as an obstacle. The manner in which the agents react to the obstacle must be both logical and deliberative.

While an agent is dancing, its mental state is constantly being updated with information regarding any potential obstacles. Once an agent detects that it is about to collide with the wall obstacle it immediately ceases all motion, notifies its fellow dancing agent of the present situation and proceeds to change its movements in order to avoid the potential collision. Once this goal has been achieved the agent informs its dance partner of this success and the dance resumes with a routine modified to take into account the position of the obstacle as illustrated in Figure 5.

The dancing scenario acts as a platform to demonstrate the capability of each agent to both reason in an independent deductive fashion and to socially collaborate with other agents in order to achieve a set goal. These capabilities are achieved through the virtual senses that the agents possess within their embodied form.

5 Future Work and Conclusions

The NeXuS framework is a dynamic and highly expandable system. Each new addition to the framework allows for more intricate scenarios to be created and experimented with.

We plan to further develop ‘Axe Game’ to give agents the ability to aid players by moderating their actions. Future developments are also planed for the ‘Dancing’ Scenario , including the addition of a third dancer in the form of a human collaborator in the physical realm. It is intended to allow the human to interact with the scenario in two different ways. Firstly as a physical world object that the embodied agents’ virtual forms must strive to evade with the use of the same avoidance strategy discussed in subsection 4.3. Secondly it is desired to modify the system to allow the human to teach the agents additional dance routines. The effort involved in the implementation of these extensions to this scenario is significantly reduced due to the modular nature of the existing NeXuS framework.

By way of three experimental scenarios, we have shown how visually animated representations of the internal responses to the external environment can lead to an increased sense of behavioural realism within the system. It is by improving an avatar’s behavioural realism that
NeXuS addresses the traditional disconnect between the physical world of humans and the virtual world of agents. Hence the embodiment of our agents within avatars situated within an Augmented reality framework can achieve the goal of delivering Behavioural Realism. This bring us closer to the NeXuS goal of creating an environment that fuses the virtual with the physical, thus allowing digital agents and real world users to fully interaction to their true potential.

Acknowledgements

Gregory O’Hare gratefully acknowledges the kind support of Science Foundation Ireland under Grant No. 03/IN.3/I361.

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