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Title	NeXuS: delivering behavioural realism through intentional agents
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Publication date	2005-05-19
Publication information	O'Hare, G. M. P. (Greg M. P.), Abraham G. Campbell, and John W. Stafford. "NeXuS: Delivering Behavioural Realism through Intentional Agents." IEEE, 2005.
Conference details	The 3rd International Conference on Active Media Technology, May 19th-21st, Kagawa, Japan, IEEE Press, 2005., Kagawa, Japan, May, 2005
Publisher	IEEE
Item record/more information	http://hdl.handle.net/10197/4482
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Publisher's version (DOI)	10.1109/AMT.2005.1505402

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NeXuS: Delivering Behavioural Realism through Intentional Agents

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Abstract

This paper explores the challenge of delivering Behavioural Realism to embedded avatars. An agent based approach is adopted and demonstrated within a Mixed Reality (MR) environment. The realism of an avatar is driven by the state of the intentional agent that underpins its behaviour. The traditional disconnect often found with avatars that exhibit shallow levels of behavioural realism is no longer evident.

1. Introduction

This paper introduces Behavioural Realism whereby the actions of situated virtual characters within Virtual and Mixed Reality environments are underpinned by some plausible and rational behavioural model.

To date the literature abounds with studies and research that addresses visual realism and associated issues. While this is undoubtedly of great importance it is our conjecture that behavioural realism is a stronger notion, the absence of which cannot be compensated for by any degree of visual realism.

This paper introduces the NeXuS Architecture [8] a multi-layered architecture that facilitates the design and delivery of multi-character Virtual and Mixed reality scenarios. The behaviour of such avatars is governed by a Multi-Agent Systems (MAS) approach whereby Intentional agents of the Belief Desire Intention (BDI) genre underpin character behaviour. Such avatars are said to be situated within the world, and based upon environmental perceptions update a mental model (beliefs) of their environment. This mental model directly drives future directed actions (commitments).

We situate this research within the broader research landscape. We examine and describe the NeXuS architecture and illustrate how behaviour of a plausible and believable nature is controlled by the intentional agent apparatus. Two

simple representative scenarios are used to animate the operation of NeXuS and offer a glimpse into its future potential.

2. Related Work

The origins of contemporary Mixed Reality are often attributed to Ivan Sutherland [10] who developed Sketchpad at MIT. This Computer-Aided Design (CAD) program enabled the user to draw directly onto the display screen with the use of a light pen. Recent developments in Augmented Reality (AR) have begun to offer a unique and intriguing method of interaction with both virtual and real artefacts.

One exemplar of this development is the Augmented Round Table for Architecture and Urban Planning, ARTHUR [9]. ARTHUR allows multiple viewers to build and modify virtual architectural models within an AR environment. Users may view the models on top of a table through the use of a Head Mounted Display (HMD) unit. Each user has the ability to manipulate the scene by moving a models physical placeholders or by using simple pen and finger gestures. ARTHUR provides a clear example of the problem in facilitating the perception of spatial and temporal representations. Participants' perceptions of concepts being explained through teleconferencing can similarly be facilitated through such technologies, particularly when the communication medium is primarily display based [1].

Historically we have witnessed a disconnect between the avatar or visual container and the cognitive processes that drive behaviour of such containers. Prior research has addressed this disconnect notable as such work as Synthetic Characters at MIT-ML [2] and the Agent Chameleons project [7]. One way of addressing this disconnect is to have a system that appears to an observer to behave in a rational and realistic manner. Much work to date has been dealt primarily with visual realism (e.g. lightning models [11]). Even systems that are designed to promote behavioural realism focus strongly on physical modelling concepts such as inverse kinematics [13] within a purely virtual domain.

Figure 1. NeXuS system architecture

Vinayagamoorthy [12] claims 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 and this definition of ‘emotion’. A BDI agent’s belief systems are influenced by both the events occurring within its environment and its own set of beliefs and desires (corresponding to ‘knowledge’). NeXuS places a strong emphasis on the detection and generation of behaviourally realistic mental (‘emotional’) states. Once the mental state has been established, the appropriate visual response can be expressed by the avatar that the agent embodies. In order to obtain such mental states, NeXuS embeds BDI Agent Factory [6] agents into an augmented reality (AR) environment thus allowing the virtual avatars situated within in this environment to dynamically perceive and react to changes in both virtual and physical domains.

3. Architecture

NeXuS constitutes an architecture (Figure 1), together with an associated methodology, that facilitates the design and delivery of experiments and experiences that fuse phys-

ical and virtual spaces into a coherent singular mixed reality employing agent based technologies. The NeXuS system is comprised of a number of customisable hardware and software components that facilitate a rapid design and build cycle. In order to facilitate a highly customisable set of components, NeXuS adopts a three-tiered architecture that allows for flexibility in modifying already installed components or indeed adding new components to enhance the system. Each layer of this architecture shall now be discussed, 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 [6], 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. Before addressing the agents that are embedded within the AR environment and their individual roles within the system, we will first address the question of what an agent is.

The word agent is one that is regularly encountered in daily life to describe people that fulfil certain specific roles, such as a travel agent or an estate agent. Many see agent-oriented programming as a natural evolution from the object-oriented metaphor. While objects may be broadly seen as tools with a set of methods and attributes, agents may be portrayed in a similarly broad sense as autonomous programs designed to work within a given role. The notion of agency is a vague one, thus making the task of delivering a formal definition of what an agent is very difficult. A major contributor to this vagueness is the fact that the word agent is often used as ‘an umbrella term for a heterogeneous body of research and development’ [5]. Despite this inability to reach a general consensus on what constitutes an agent, Wooldridge and Jennings have compiled a list of attributes that may be associated with agents. According to Wooldridge and Jennings [14], an agent may not be considered as such unless it conforms to the ‘weak notion’ of agency that entails the attributes of Autonomy, Social ability, Reactivity and Pro-activity. Wooldridge and Jennings also propose a set of attributes in [14] that make for a stronger notion of agency. These attributes include, but

are not limited to mobility, veracity, benevolence and rationality.

The agents used within NeXuS are BDI agents. BDI agents are so-called because they possess mental attitudes of Belief, Desire and Intention, respectively representing the information, motivational and deliberative states of the agent. Beliefs are the informative component of the system state, representing the information the agent has on the current state of its environment. These beliefs are updated every time the environment is screened for changes. Desires are the motivational component of the system state, representing information about objectives to be accomplished by the agent. Intentions are the deliberative component of the system state, representing the agent's currently selected course of action. BDI agents are highly suitable for a rich active media environment such as that supported by NeXuS due to their highly pro-active nature.

The most significant agent in the middle NeXuS architectural layer is the viewer agent. The viewer agent is so-called because it views the world for the other system agents. This agent's perceptors constantly scan the world for changes. Such changes are acted upon by way of the viewer agent communicating the relevant information to the other system agents. The viewer agent also maintains communication from the agent layer to the world layer. An example of such a communication would be the Mr. Potato Head agent wishing to move a certain distance to the left of its current position. In order to do so the Mr. Potato Head agent must inform the viewer agent that it requests to move left. Upon receipt of this communication, the viewer proceeds to change the position of the Mr. Potato Head model in the world. This move operation would produce a change in the world state thus requiring the viewer agent to inform the other system agents (including the Mr. Potato Head agent) of the current state. NeXuS has the ability to run in two distinct modes. The first scenario that is addressed is one whereby all agents are concurrently present upon the same machine. The second such scenario facilitates the ability of agents on different machines to share a common NeXuS experience. In this shared scenario a second viewer agent is set up on an independent Agent Factory runtime environment running on the secondary machine(s). The agents which are embodied within the environment can be run from either platforms but inhabit the same mixed reality world.

3.3. World Layer

The top 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 common place usage of VRML and dynamic update via the External Authoring Interface (EAI).

The ARToolKit [4] marker based augmented reality toolkit is used to support both video input and the sensing of events in the physical world. This toolkit was used to make several different markers for the NeXuS project. To integrate the C based ARToolKit with Java3D, an open-source java binding called jARToolKit was used. The original version of jARToolKit was developed by C-Lab in Germany.

To facilitate vocal interaction with the system a speech perceptor was added to the Mr. Potato Head agent. This initial perceptor was designed to interpret output from IBM's ViaVoice speech recognition software. In order to demonstrate the flexibility of the NeXuS architecture to incorporate new technologies, a second speech perceptor was implemented using Sphinx-4. Sphinx-4 is an open source speech recogniser that is implemented through java and developed by Carnegie Mellon University. The primary advantage in using Sphinx-4 is that it will allow far more potential control over the speech recognition features of NeXuS by way of both its dynamic grammar facilities and its generic speech recognition model.

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 mixed reality environment in which the agents are embodied.

The principle input technologies in the physical domain are the camera and the microphone. A Logitech Quickcam Express camera running at 30 frames per second and at a resolution of 352 x 288 pixels is positioned on a users head. This acts as the visual input for the HMD. When displaying the NeXuS system on a regular monitor, the Logitech Quick-Cam Orbit camera provides the live video streams. In both the HMD and monitor scenarios the audio input facilities are supplied by the built in camera microphone. Both the audio and video input from the physical components of the world layer is continuously processed by the virtual level components. The video stream is polled once every thirtieth of a second while the audio is polled for full utterances every twentieth of a second. The main physical output device is the display unit, which may take the form of either a monitor, a HMD or a projector. The concept of a video see through display is used with respect to the HMD.

Figure 2. Snapshot of mental and visual state of the teenager

The particular model of HMD used by NeXuS is a Cyber-Mind hi-res 900. The combined image of both the camera input and a 3-D graphics overlay is displayed on the particular output device.

4. NeXuS System Behaviour

In order to animate the NeXuS architecture we will consider two simple though sufficient scenarios, namely the Flashlight scenario and the Axe Game scenario. In the description of each we focus upon the transition of the agent mental state associated with each character. This mental state evolves to reflect the perceptors of Virtual world agents by the given Virtual character. The agent adopts commitments which subsequently fuel future directed actions. Such actions are thus grounded in realism resulting in rational and plausible situated behaviour.

4.1. The Flashlight Scenario

The first of these two NeXuS scenarios involves an avatar of a teenager deliberately deciding to *dodge* the virtual glare of a marker given the attributes of a physical flash light. The purpose of this experiment is to illustrate how BDI agents can perform deliberative actions based upon their current mental state of beliefs and desires.

It is desired to show the teenager agent avoiding the light in a logical, behaviourally realistic manner. The teenager agent achieves this type of behaviour by processing information on both its own position relative to the flash light and vice versa. If the light is *shining* straight on the teenager agent's avatar, it moves in a randomly chosen direction until it gets to a point where the flash light's *beam* is either to its left or right hand side. At this point it deliberately chooses

to move in the opposite direction of the light source. If the flash light changes its position during the movement of the teenager avatar, the embodied agent will react accordingly and change its movement pattern.

Figure 2 illustrates a montage of the teenager agent's beliefs, commitment rules and the resulting commitments for a given time step. This figure also displays the world as seen from the point of view of the user along with the Agent Factory agent platform viewer. The simple beliefs of *BELIEF(See(light))*, *BELIEF(SeesU(Light))* and *BELIEF(PositionU(Light,left))* respectively correspond to the agent seeing a light in front of them, realizing the light is orientated in their direction and that they are positioned to the left of the light's field of view. The three commitment rules (also shown in Figure 2) process these beliefs and generate a new set of beliefs that invoke a change in both the visual and mental state of the teenager agent. The first commitment rule is invoked if the agent believes that:

- i A light is in front of the agent;
- ii It is a member of the Teen ontology;
- iii The light is orientated towards it;
- iv It has not previously decided an action for this situation;
- v It is positioned on the left hand side of the light's field of vision.

Once these requirements are fulfilled the teenager agent generates the belief *BELIEF(IChoose(right))*. This new belief causes the teenager avatar to move to its right hand side. From the light's perspective the teenager appears to be moving constantly left until it has moved outside of the light's visual range. The second commitment rule in Figure 2 can

Figure 3. The teenager moving away from the light

be invoked once the light can no longer view the teenager avatar. This commitment rule is responsible for changing the state of the teenager agent to incorporate the belief *BELIEF(AwayFromTheLight)*. The third commitment rule allows for the possibility of the teenager agent invoking its avatar to cover its eyes with its hands when the light is ‘shining’ on it and to conversely uncover its eyes when it is no longer within range of the light’s *beam*. Figure 3 depicts the teenager avatar’s light beam evasion behaviour. As can be seen Figure 3 (I) through figure 3 (IV) illustrates its movement across time as it perceives the virtual light beam. 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. Within this environment an embodied agent is able to display complex behaviours based upon a relatively simple set of beliefs, commitments and commitment rules (corresponding to beliefs, desires and intentions). It is in this sense that NeXuS shares a common goal with the Autonomous Robot community wherein it is believed that complex behaviour does not come from a complex control mechanism but from a complex environment [3].

4.2. The Axe Game Scenario

This second NeXuS scenario demonstrates how BDI agents can be used to mediate interaction between the physical world and the virtual avatars. The BDI 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. Once the relevant markers are placed within the visible world their corresponding avatars visually manifest themselves. The avatars remain as purely visual ‘empty shells’ until their embedded agents are activated by way of the Agent Factory platform viewer.

The Mr. Potato Head and Teenager agents automatically generate registration requests with the viewer agent at activation time. Once the viewer agent has confirmed their registration details the human user obtains the ability to participate in the axe game. The NeXuS system records axe throws, impacts and misses in a scoring system. This process starts when the user issues a fire voice command and a belief is generated. Once a fire command has been given, the belief state of Mr. Potato Head is updated and triggers off a series of communications between itself and the viewer agent resulting in the creation of a virtual axe. In order to improve realism, the apparition of the axe occurs from the same position as Mr. Potato Head thus giving the visual appearance of Mr. Potato Head throwing the axe.

The thrown axe rotates as it travels in a straight line from its point of origin and remains in the world for twenty seconds. Until an axe throw has hit the teenager model the system assumes that it has missed. If the viewer agent believes that the global position of the axe intersects with that of the teenager, it informs both the Mr. Potato Head and teenager agents of this occurrence.

While a hit only changes Mr. Potato Head’s beliefs regarding the game score, a more complex reaction occurs within the teenager agent. Not only does the teenager change its score beliefs, it also must appear to fall down. In order to perform this action the viewer agent must be in-

Figure 4. Teenager colliding with axe

formed of the teenager's wish to change its current animation from standing to falling as seen in Figure 4.

5. Conclusions and Future Work

The pursuit of behavioural realism is a laudable goal though one fraught with computational complexity. Many factors influence and enhance the sense of authentic behaviour but above all the ability of the avatar to perceive their environment and act in a manner commensurate with those perceived events. The perceive, deliberate act cycle is central to attaining behavioural realism and it is this very deductive cycle which lies at the heart of the intentional agent apparatus. In BDI agents environmental events can manifest themselves in the form of communicative events (receipt of messages, informs or requests) or physical events based upon perceptions. In a similar sense our embodied agents perceive communicative and virtual events.

The example scenarios that we have considered are simple yet illustrative of the underlying power of the NeXuS architecture. Future work is examining the representation of agent emotions and the correlation between avatar behaviour. By way of example certain emotional states may lend themselves to certain behaviours happiness may result in smiling and a collaborative disposition while a stressed state may result in frowning and a curt conversational manner. Of more interest is how the character may evolve both in terms of the agent's perception of self and its perception by others. Clearly as entities their character will emerge based on world experiences comparable to the human context. Thus observers of the behaviour of a given avatar have prior expectations as to anticipated actions based upon world events. These behaviours would be expected to be in keeping with their character. Future work will describe ongoing work in this regard.

6. Acknowledgements

Gregory O'Hare would like to gratefully acknowledge the kind support of Science Foundation Ireland under Grant

No. 03/IN.3/I361.

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