

Intentional Embodied Agents

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Abstract

Virtual environments present a suitable platform for the deployment of agent technologies. We advocate a system of virtual agents that are capable of changing their form in order to expand their capability sets. We use strong BDI agents for the control of this adaptation of form and behaviour. This paper outlines a system that allows for adaptable virtual agents, with the ability to change their form to suit the task at hand based upon deliberative reasoning.

Keywords: Virtual Environments, Virtual Agents, BDI, Body-Form, Embodiment.

1 Introduction

This paper proposes a system in which agents located within virtual environments are controlled by a *Belief-Desire-Intention* (BDI) architecture [1]. These agents are embodied through an *avatar*, a graphical representation of the agent within the virtual environment. We define the agent's *body-form* as the form of a body that an agent can choose to adopt. The set of actions that an agent can perform is defined by its body-form, each body-form having its own set of capabilities. Traditionally agents are only provided with one choice of body-form, thus limiting the agent's set of capabilities. This research

aims to provide agents with the ability to judiciously change their body-form to suit the task at hand. The agent is provided with access to a range of different body-forms each with their own capabilities and advantages.

This work is influenced by other virtual agent systems such as MAVE [2] and MIAU [3], as well as those based upon BDI reasoning, including VITAL [4] and systems developed by Torres et al. [5] and Huang et al. [6]. This research forms part of the Agent Chameleons project [7, 8], which endeavours to create the next generation of virtual agents, autonomic entities that can seamlessly migrate, mutate and evolve between and within virtual information spaces.

This paper outlines an architecture that supports these virtual agents, providing them with the ability to change body-form and subsequently illustrates their operation in relation to a virtual science museum application.

2 Architecture

The selection of an agent's body-form is a vital decision for the agent. Different body-forms serve different roles, providing the agent with different abilities in its interaction with the virtual world as well as with the user. Body-forms must also preserve the agent's sense of identity within the mind of the user [9]. It is therefore essential that the agent is capable of deliberating upon its choice. These requirements are addressed by our architecture, shown in figure 1.

This architecture has been designed to be as

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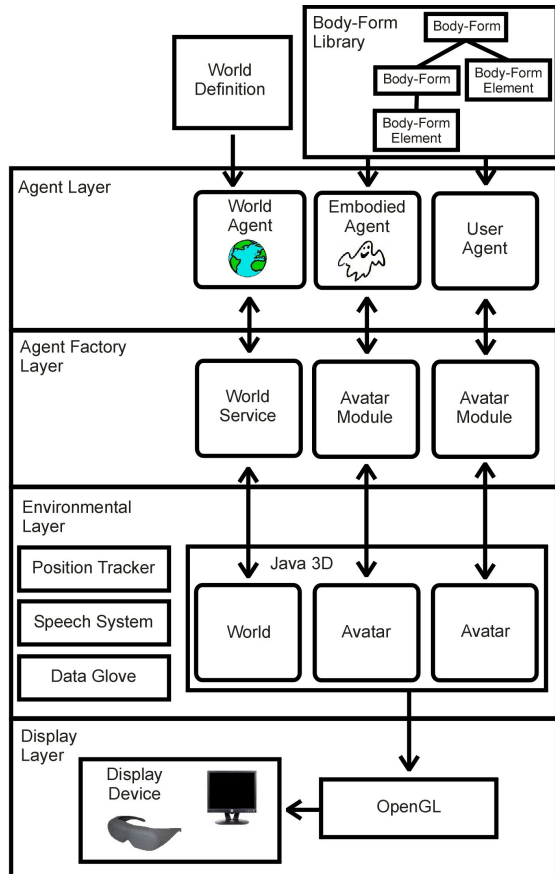


Figure 1: The system architecture.

generic as possible, so that various applications can be easily developed using it. The world’s creator (referred to as the *designer*) needs to define the topography of the world, the possible body-forms that virtual agents can adopt, and their behaviour.

The agents’ deliberative mechanism is based upon Agent Factory [10], which provides a cohesive framework for the development and deployment of agent-oriented applications using BDI agents across a large number of platforms. Reasoning within agent factory is based upon a series of beliefs. A *belief* is in effect a representation of what the agent believes to be true at the current moment. A belief “the agent believes that the sky is blue” is represented by:

```
BELIEF ( sky ( blue ) )
```

A *commitment* represents an agent’s pledge to assume a course of action. Commitments represent the outcome of the agent’s decision-making process. They are generated by the agent based

upon its beliefs and *commitment rules*, rules that define the circumstances under which the agent adopts a particular commitment. The commitment rule “if the agent believes that it is raining, and believes that it has an umbrella, then it will commit to raising an umbrella” is represented by:

```
BELIEF ( weather ( rain ) )
& BELIEF ( have ( umbrella ) )
=> COMMIT ( raise ( umbrella ) )
```

Within Agent Factory, *Perceptors* are responsible for the generation of beliefs based upon the environment, and *actuators* are responsible for changing the environment in response to the agent’s commitments. A *module* is an external block of code that can be used to share functionality and memory between actuators and perceptors of an agent, and a *platform service* is a mechanism for implementing a shared resource that may be utilised by multiple agents.

There are three key agent roles in this system, the world agent, the user agent and the embodied agents. The *world agent* is responsible for the creation and maintenance of the world. It selects the world definition that is to be used, controls the body-form library and selects the display devices that are to be used. An *embodied agent* is responsible for the control of an avatar, it is the mind of the virtual agent. The embodied agent selects the body-form of the agent and controls the avatar within the world. The *user agent* represents a user within the world. It has all the abilities of the embodied agent, but takes commands directly from the user rather than its own deliberation.

A *world definition* defines the geometry of the environment, it is a java class, created by the designer that specifies the world geometry as a Java3D scene graph. The scene graph can include any necessary behaviours to control action within the world and allow response to agent and user interaction. The world definition also defines any *world properties*, facts about the world that can change over time, possibly in response to user or agent actions, that embodied agents are informed of (e.g. the weather of the world). An Agent Factory platform service, called the *world service*, is used to control the world. It creates the world based upon the world definition and display devices selected by the world

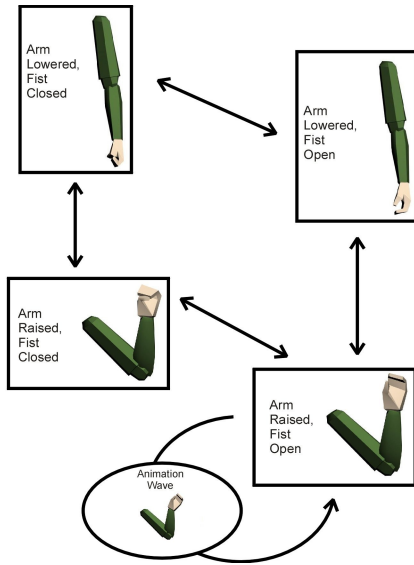


Figure 2: An example animation state graph.

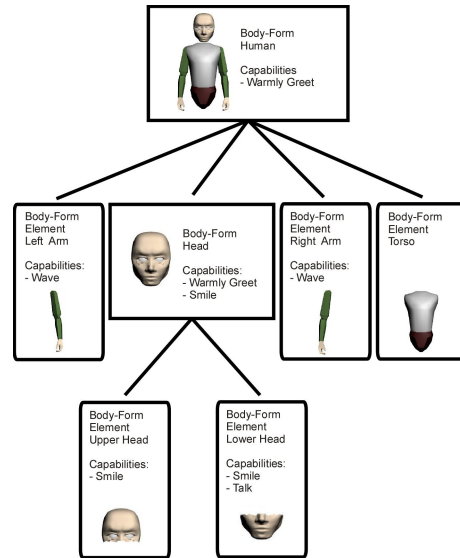


Figure 3: A sample body-form tree.

agent and serves as an access point to the world.

The *body-form library* contains a collection of body-forms that embodied agents can adopt. A body-form is a tree, internal nodes are themselves body-forms and the leaf nodes each correspond to a definite piece of geometry and are referred to as *body-form elements*. Each body-form element is capable of animation, and can define a number of animation states, points at which the geometry is in a common position and the animations can be stitched together. These are linked to other states by animations, forming a directed graph that the embodied agent can traverse, executing animations. At any point the current animation state defines the sets of animations that the agent can execute. A simple example of one of these animation graphs is illustrated in figure 2.

Both body-forms and body-form elements can also have associated *capabilities*, abilities to perform a particular action. When an agent adopts a body-form it gains all the capabilities associated with its tree. The choice of body-form thus affects not only the appearance of the agent but also its ability to act. Capabilities could involve animation of the avatar, external action through the use of an Agent Factory actuator, or a combination of both. Generic capabilities are also possible, such as “warmly greet” or “sleep”, and can be present in multiple body-forms but produce different actions in each. A

sample body-form is shown in figure 3.

In order to allow the designer to easily create body-forms, the various nodes of the tree can be defined in a series of XML files, either *body-form element descriptor* (BFED) files, corresponding to body-form elements, and *body-form descriptor* (BFD) files, corresponding to body-forms. Each BFD file consists of references to the BFD or BFED files that form the next level of the body-form’s tree, a BFED must also contain references to the geometry and texture files that form that element.

To facilitate this animation, each element has an associated time-line, and each of the geometry files is assigned a particular key point on that time-line within the BFED. Animations are then defined by providing a start and end point from this time-line, and can then be carried out by interpolating between the geometries that define the key points. The nodes of the directed animation graph, the animation states, can then be defined using these animations as possible links. The BFD and BFED files can also be used to define the capabilities of the body-forms.

An animation ontology such as this affords the designer ease of control over the form and function of the various body-forms available to the agents in the environment. It should be noted that the factors defined in these files can be changed dynamically by the embodied agent as it sees fit, once the body-form has been in-

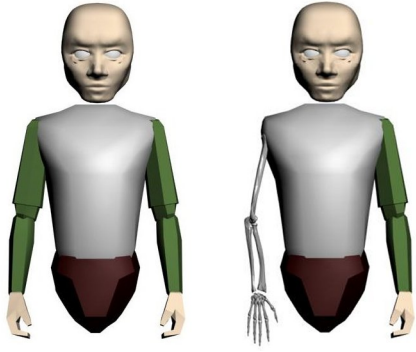


Figure 4: The agent replaces its arm with a skeletal one.



Figure 5: The agent greets the user.

stantiated as an avatar. For example the agent can reduce the granularity of the interpolation between frames, or turn off some unnecessary body-form elements, when necessary.

Each embodied agent has knowledge of the capabilities of the available body-forms and can select the one most suitable to its task, which is instantiated as the agent's avatar, its embodiment. An *avatar module* controls this avatar and acts as an access point to it for the agent. The avatar is itself a tree, identical in structure to that of the body-form that has been adapted. However, unlike the body-form trees, the avatar tree is a dynamic entity; the embodied agent has deliberative control over the avatar at each of the levels in the tree and can manipulate either specific elements or entire groups. Branches of the tree can also be added and removed by the agent as necessary. Body-forms can be classified into groups (e.g. head, arm) and one group member can be replaced by another, as in figure 4.

The embodied agent has a number of perceptrs that generate beliefs about the state of the avatar, the animations and capabilities available

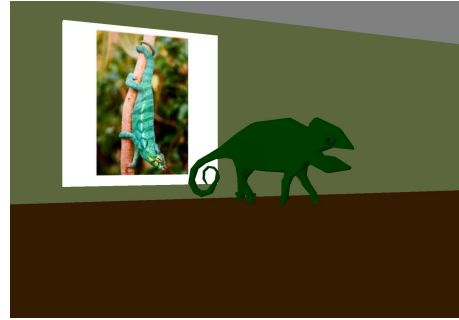


Figure 6: The agent illustrates chameleon motion.

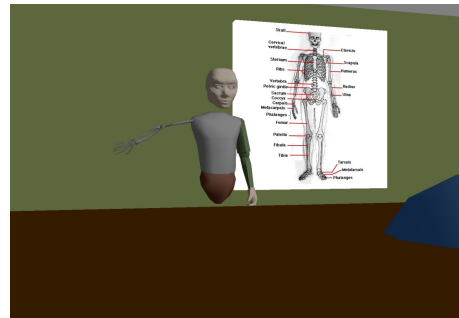


Figure 7: The agent illustrates the motion of the various joints in the arm.

and other body-forms that can be adopted, as well as beliefs regarding the environment. It also has actuators that allow the agent to change its form, invoke animations or capabilities, move through the world and interact with the user through any interaction modalities (e.g. voice capabilities). Based upon the beliefs and commitment rules, the embodied agent generates commitments to trigger actuators. An example of this in operation is shown in relation to an application within a virtual science museum.

3 Case Study: Science Museum

These virtual agents have been used as guides within a virtual science museum. As the user moves between exhibits the agent changes body-form to illustrate different points. The agent adopts a human body-form when it wants to interact with the user (figure 5), a chameleon form to illustrate the motion of a chameleon (figure 6), and a human with the arm replaced by a skeletal one to demonstrate the motion of the various joints in the arm (figure 7).

If the agent adopts the human body-form, its avatar tree is created with a structure identical to that of the human body-form, as shown in figure 3. The embodied agent's perceptors then generate beliefs as follows:

```

BELIEF(currentBodyForm(Human))
BELIEF(subBodyFormElem(Human.rightArm,
rightArm))
BELIEF(subBodyFormElem(Human.Head,
head))
BELIEF(subBodyFormElem(
Human.Head.upper))
BELIEF(possibleAnimation(
Human.rightArm, raise))
BELIEF(possibleAnimation(
Human.rightArm, closeFist))
BELIEF(capability(Human, warmlyGreet))
BELIEF(capability(Human.Head,
warmlyGreet))
BELIEF(capability(Human.Head, smile))
BELIEF(capability(
Human.Head.lower, smile))
BELIEF(capability(Human.rightArm,
wave))
BELIEF(possibleBodyForm(Chameleon))
BELIEF(possibleBodyForm(SkeletalArm,
rightArm))
BELIEF(possibleBodyForm(Robot))
BELIEF(allowedMotion(X))
BELIEF(allowedMotion(Y))
BELIEF(location(self, 0, 1.4, 0))
BELIEF(location(user, 2.0,
1.9, -1.2))
BELIEF(at(user, chameleon))

```

These include beliefs about the form of the avatar, the structure of the avatar tree, the possible animations and capabilities of the avatar, and other body-forms that can be adopted. These also include beliefs about the environment, including beliefs about the agents location and possible motion, input devices such as a data glove and the location of the user and other agents in the environment.

If the agent gains a belief that the user has approached the skeleton exhibit (BELIEF(at(user, skeleton))) and has the following commitment rule:

```

BELIEF(at(user, skeleton))
& BELIEF(possibleBodyForm(SkeletalArm,
rightArm))
& BELIEF(subBodyFormElem(?any,
rightArm))
=> COMMIT(adoptBodyForm(SkeletalArm,
rightArm))

```

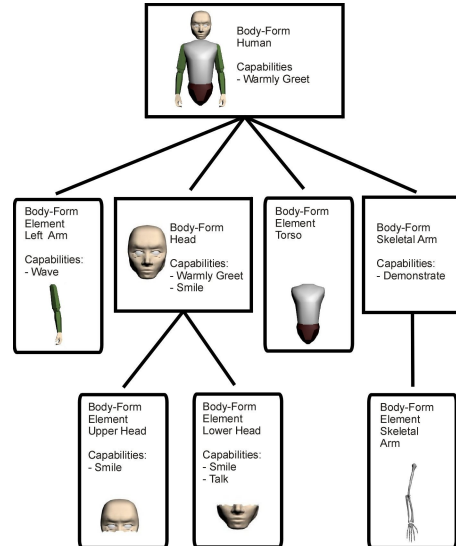


Figure 8: The updated avatar tree.

It then commits to replacing it's arm. An actuator replaces the avatar's right arm with a skeletal one. The avatar tree is then as in figure 8 with beliefs regarding the right arm replaced by:

```

BELIEF(subBodyForm(Human.SkeletalArm,
rightArm))
BELIEF(subBodyFormElem(
Human.SkeletalArm.arm))
BELIEF(possibleAnimation(
Human.SkeletalArm.arm,
demonstrateElbow))
BELIEF(possibleAnimation(
Human.SkeletalArm.arm,
demonstrateShoulder))
BELIEF(possibleAnimation(
Human.SkeletalArm.arm,
demonstrateWrist))
BELIEF(capability(
Human.SkeletalArm, demonstrate))

```

The agent could now commit to animating the arm, or a full demonstration of the arms movement, using one of the following commitments:

```

COMMIT(triggerAnimation(
Human.SkeletalArm.arm,
demonstrateShoulder))
COMMIT(actOnCapability(
Human.SkeletalArm.arm, demonstrate))

```

4 Conclusion

This paper has described an agent based approach for the control and influence of avatar

behaviour. We advocate the use of strong BDI based agents as a mechanism for the dynamic and opportunistic adaption of agent form and behaviour. Body-forms are represented as an aggregation of constituent parts, organised into a tree structure, associated with each level of which are a set of behaviours and capabilities. The agents are capable of judiciously adapting their body-forms in order to utilise the facilities of each. A rich agent mental state underpins such avatar behaviour.

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References

- [1] Anand S. Rao and Michael P. Georgeff. Modeling rational agents within a BDI-architecture. In J. Allen, R. Fikes, and E. Sandewall, editors, *Proceedings of the Second International Conference on Principles of Knowledge Representation and Reasoning - KR 91*, San Mateo, CA, USA, 1991. Morgan Kaufmann.
- [2] Jeffrey Cobel and Karen Harbison. MAVe: A multi-agent architecture for virtual environments. In *Proceedings of the Eleventh International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems*, pages 577–583, 1998.
- [3] Thomas Rist, Elisabeth André, and Stephen Baldes. A flexible platform for building applications with life-like characters. In *Proceedings of the Eight International Conference on Intelligent User Interfaces - IUI 2003*, Miami, Florida, USA, January 2003.
- [4] George Anastassakis, Tim Ritchings, and Themis Panayiotopoulos. Multi-agent systems as intelligent virtual environments. In *Proceedings of Advances in Artificial Intelligence, Joint German/Austrian Conference on AI - KI 2001*, volume 2174 of *Lecture Notes in Computer Science*. Springer, September 2001.
- [5] Jorge A. Torres, Luciana P. Nedel, and Rafael H. Bordini. Using the BDI architecture to produce autonomous characters in virtual worlds. In *Proceedings of the Fourth International Working Conference on Intelligent Virtual Agents - IVA 2003*, volume 2792 of *Lecture Notes in Computer Science*, pages 197–201, Irsee, Germany, September 2003.
- [6] Zhisheng Huang, Anton Eliëns, and Cees Visser. Programmability of intelligent agent avatars. In *Proceedings of Agent'01 Workshop on Embodied Agents*, Montreal, Canada, June 2001.
- [7] Brian R. Duffy, Gregory M. P. O'Hare, Alan N. Martin, John F. Bradley, and Bianca Schön. Agent chameleons: Agent minds and bodies. In *Proceedings of the Sixteenth International Conference on Computer Animation and Social Agents - CASA 2003*, New Jersey, USA, May 2003.
- [8] Gregory M. P. O'Hare, Brian R. Duffy, Bianca Schön, Alan Martin, and John F. Bradley. Agent chameleons: Virtual agents real intelligence. In *Proceedings of the Fourth International Working Conference on Intelligent Virtual Agents - IVA 2003*, volume 2792 of *Lecture Notes in Computer Science*, pages 218–225, Irsee, Germany, September 2003.
- [9] Alan Martin, Gregory M. P. O'Hare, Brian R. Duffy, Bianca Schön, and John F. Bradley. Maintaining the identity of dynamically embodied agents. In *Proceedings of the Fifth International Working Conference on Intelligent Virtual Agents - IVA 2005*, Kos, Greece, September 2005.

- [10] Rem Collier, Gregory M. P. O'Hare, Terry Lowen, and Colm Rooney. Beyond prototyping in the factory of agents. In *Proceedings of the Third Central and Eastern European Conference on Multi-Agent Systems - CEEMAS'03*, Prague, Czech Republic, 2003.