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RICHARDS, Debbie, *et al*.

RICHARDS, Debbie, *et al*. Impacts of Visualisation, Interaction and Immersion on Learning using an Agent-Based Training Simulation. *International Transactions on Systems Science and Applications*, 2008, vol. 4, no. 1, p. 43-60

Impacts of Visualisation, Interaction and Immersion on Learning using an Agent-Based Training Simulation

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Abstract: Simulations offer a safe, repeatable and controlled way of providing training to humans and for evaluating the value of the training. This paper describes a simulation system that we are developing for the purposes of training customs officers to identify risk situations. The work brings together research from virtual environments; narrative intelligence; language technology and knowledge acquisition to develop a training system we are using to evaluate the effect of factors on our architecture and implementation such as visualization, interaction, and immersion on engagement and learning.

Keywords: agent based systems, simulations, training, virtual environments, knowledge acquisition, language technology, narrative intelligence, engines and storytelling.

1. Introduction

With the development of computer technology, simulation has become more and more widely used in many fields of society. Simulation techniques not only play important roles in scientific study, but also occupy important places in education, military training, entertainment and almost any field imaginable. The basic concept of simulation is a technique of imitating the behaviour of some situation or process (whether economic, military, mechanical, etc.) by means of a suitably analogous situation or apparatus, e.g. for the purpose of study or personnel training. Computer based simulations are today used in a variety of fields, supported by a growing simulation industry.

Agents are currently being applied in domains as diverse as computer games and interactive cinema, information retrieval and filtering, user interface design, electronic commerce, autonomous vehicles and spacecraft, and industrial process control. Using agents to manage a training simulation takes advantage of their characteristics, including being **autonomous, reactive** and **proactive** and having **social ability**. An autonomous characteristic means that agents can operate without the direct intervention of humans. Reactivity means that agents can perceive their environment and respond in a timely fashion to changes that occur in it. Pro-activeness enables agents to not simply act in response to their environment, but be able to exhibit goal-directed behaviour by taking the initiative. Social ability means that they can interact with other agents.

Our project is focused within the domain of risk assessment for customs officers, where the goal of the system is to allow the user to learn to identify suspicious behaviour and ultimately decide whether the aircraft passenger should be allowed to enter the country or not. To provide a simulated training environment for customs officers requires tackling a number of different challenges. By using an agent-based architecture we can take a divide-and-conquer, modular approach which allows alternative components and solutions with varying levels of intelligence and sophistication to be combined and tested. The virtual reality (VR) training systems for customs officers we have developed have become vehicles for exploring the potential benefits of VR technology for learning. Virtual reality is a medium composed of interactive computer simulations. Control is a key element of interactivity. We have employed concepts from narrative intelligence to support the flow of control between the system, user and training content within our simulation.

There are three major characteristics of a virtual reality application: Visualisation, Interaction and Immersion [37]. Immersion is maintained at least in one sensory modality, such as vision. Early simulation systems were mainly based on visualisation. Later this has been replaced with immersion. Interaction allows direct manipulations of objects in a virtual environment. We are conducting experiments to test each of these characteristics using our agent-based architecture and implementation.

In this paper, we first discuss the notion of simulation and review some of the simulations used for training in section 2. In section 3 we introduce our methodology and approach including the underlying fields of research relevant to developing a training simulator. In section 4 our agent architecture is introduced. A number of studies we have conducted to test certain factors relating to training simulations are described in Section 5. Discussion, comparison, and conclusions are given in the final sections.

2. Simulations

The simulation industry presently produces simulation software for a variety of purposes, ranging from military training to management, dynamic systems engineering, computer games and the production of networked environments. The usage of computerized simulations ranges as far back as graphic computers, for example, the US Military developed a modified version of the electronic game *Doom* called *Marine Doom,* as a target practice simulation [28] [45].

The research and development sections of military institutions worldwide used to be the primary development ground for new simulations, however, in the past two decades the civilian industry has rapidly outgrown the military budgets. In recent years, the computer games industry has come to dominate the publicly known simulation market, and currently institutions such as the military are attempting to harvest the results of the massive research and development in the games industry. Apart from the military and games sectors, engineering companies, medical suppliers, emergency responders, education technology specialists and other groups are heavily engaged in the development of simulations for a variety of purposes, to the extent where the non-game part of the civilian sector outranks the military and games sectors [85].

2.1 Types of Simulations

Simulation is a method for implementing a model over time [71]. Rothwell and Kazanas [68] defined a simulation as an "artificial representation of real conditions". Simulations form a type of learning process utilizing computers, intended to be engaging, educational and highly interactive. Even where training is not the goal, such as in wargames or predictive simulations, there is still an element of practicing ones knowledge and skills. It is important to realize that computer simulations cannot replace practical experience because the number of variables programmed is fewer than needed for complete reality, and the simulated environment does not feature the physical limitations of the real world. There is also a problem, common to computer-based learning and the use of technology in education in general, that while a game or simulation may be engaging the learning outcomes may not be achieved without some form of guidance or scaffolding. This is particularly true when the goal is to pass on domain concepts or facts or solve a problem.

Our goal, while seeking to provide a scenario that could actually happen, is more concerned with the user experiencing the situation than responding in the correct way. Similar to the approach in TactLang [32] which allows a measure of success to be shown discreetly on the screen, we intend to add into our system a hot/cold meter to indicate if questions or actions of the customs officer trainee are heading in the right direction. However, we are primarily interested to expose the trainee to numerous and alternative variations of multiple scenarios, enabled by using the narrative engine to control and alter flow of events within the scenario, which will lead potentially to some tacit and deep learning through reflection.

We see a tension in many computer learning environments between allowing the user to explore and learn what they chose to learn and presuming that certain concepts should be learnt and in a particular order. We see our simulations as a supplement to practical experience between the lecture room and physical training and simulation/real world, similar to the use of the HazMat simulator by fire brigade trainees to conduct training in handling emergencies before continuing to physical, staged simulations. One major advantage of these training programs is that it is cheaper to train people in a virtual environment than staging similar physical simulations (for example, training fire fighters to put out a fire that has been set to a house in a virtual environment, using technology such as Virtual Reality (VR) incurs less financial cost, none beyond runtime, in comparison to the same action in the real world).

The categorization of simulations varies from publication to publication. Farber [22] recognized two categories:

1) Experimental simulations place the learner in a particular scenario and assign the user a role within that scenario. The user takes on the role and responsibilities in a virtual environment. Thus, the user gains valuable problem-solving and decision making skills. Related to experiential simulations is **problem-based learning**, used in many medical schools.

2) Symbolic simulations depict the characteristics of a particular population, system or process through symbols. The user performs experiments with variables that are a part of the program's population. Symbolic simulations present the user with a **scenario**, and the user must formulate a response to the situation, in order to receive feedback. Many computer based training simulations are of this type.

A different set of categories were presented by Boyle [6]. He identified three types of simulations based on the level of student activity that is required. The first of these is **passive simulation**, where the student observes the operation of a simulation as it unfolds. Secondly, **exploration simulation** is where a student selects from multiple paths to navigate through an unfamiliar environment. Thirdly, **task-based simulations**, which are of the greatest educational value, are where students interact with objects or characters in realistic situations to achieve a specific goal.

Davis [17] and Prensky [60] classified training simulations into three groups: virtual, constructive and live simulations. In virtual training simulations, the user is immersed in a virtual world. In constructive simulations, tactical and strategic decisions are made testing the user's ability to use the resources effectively. Live simulations allow users to practice the physical activities with the real equipment.

2.2 Features of Simulations

No matter the categorization used, problem-based virtual reality simulations for military, police and emergency responder training share a few characteristics. We analysed the characteristics of computer games [14] and training simulations [39] and found that they share similar characteristics. It is therefore not surprising that computer games have been widely used for training simulation purposes. Crawford [14] defined a game as comprising: Virtual Representation of the Reality; Safety, Conflict and Interactivity. According to King [39], training simulations provide the user with: practice in representative aspects of real situations; a practical alternative when the real experience is too dangerous, too expensive, too slow, too rapid, or impossible to experience; a method for rehearsing what to do in stressful situations; and a method for analysing problems before taking action. Simulations provide discovery through immediate and direct feedback and give an opportunity to reproduce a chain of events that could not be repeatedly observed in a natural setting.

In our work each of these features are included with a focus on a safe virtual reality environment in which interactivity is an option and conflict exists in the form of having to chose between conflicting options relating to usage of the system and decision making related to risk assessment.

Depending on specific uses and programming, the following can also be applicable to training simulations:

- the opportunity for change and development during all sequences of the activity

- interaction among participants, if group activities are included.
- Depending on programming, they can provide:
  - informative feedback;
  - a critique or debriefing period.

There are varying degrees of VR, which add to the user's perception of reality in the simulated environment. Kavakli and Kavakli [36] found that a computer game may reinforce learning of a historical event with the presentation of a proactive and interactive learning environment that is suitable for legitimate peripheral participation. Situated learning is usually unintentional. Learners become involved in a community of practice which embodies certain beliefs and behaviours to be acquired. This is called the process of "legitimate peripheral participation". Navigation is an important concept in situated learning. Computer games emphasize active perception over concepts and representation. This may cause automated recognition of the presented facts by evoking players' attention.

The similarities and overlaps between games and simulations are often more apparent than the distinctions between them. For example, *Counter Strike* and *SWAT* combine simulations with game-rules and entertainment. We could argue that all games are simulations in the sense that they are virtual representations of real or imaginary worlds.

2. 3 Limitations of simulations

The usefulness of simulation for training is undeniable. However, from a pedagogical point of view, several limitations should be taken into account, in order to provide not only a technically achieved simulation but also efficient training software.

First, several studies have reported the difficulties of learners when faced with a simulation with no or limited guidance. Indeed, the philosophy behind simulations is to put the learner in direct contact with knowledge rather than giving him or her direct instruction. This is theoretically appealing but it raises difficulties in real cases. For example Rieber [64] reports that "adults are largely unable to learn from simulations without some forms of guidance or structure". Typically, learners would either interact with a limited subset of relevant parameters in the simulation or they would not extract from their experience what is relevant and what is not. The proper pedagogical use of simulations includes guidance. This guidance can be inserted in the software itself, but in most cases guidance is provided by teachers or tutors.

Second, agent-based simulation involves the simulation of humans, certainly the most complex "object" to model. As a consequence the training simulation targeted by this research is necessarily both partial and inaccurate. In order to work around this fundamental limitation, designers implement shortcuts. For example, an agent behaves according to a script instead of behaving according to psychologically plausible decision algorithms. The way these shortcuts are designed remains arbitrary.

Third, simulations sometimes voluntarily violate the rules of the model they represent, in order to improve the experience (in terms of pedagogy or fun for example). In some cases, these "distortions" of reality even constitute the basis of the simulation. Typically the simulation of a material (gas, fluid, solid) would show elements (particles, stress repartition, etc.) normally invisible. In agent-based simulations, what is typically biased is the probability of some events. In the domain of risk assessment for example, the designer might decide to increase the probability that characters are dangerous, in order to increase both the appeal of the simulation and its efficiency in terms of learning.

These limitations have implications in the design of an agent-based simulation dedicated to training, as we shall see.

3. The Approach

In keeping with our project goals, simulations provide a safe and viable environment for trainees [27]. We have built a simulation to allow the participant to take on the role of an actor in a drama or the protagonist in a story. While some actions will be wise or foolish, there is not necessarily one (right) way of achieving a goal or responding to an event. It is experience, not so much education, that we are wanting our trainee to gain. Unlike a chemical modeling system or flight simulator we do not seek to pass on codified knowledge about molecular structure or even tacit knowledge relating to the skill of flying. Our simulation becomes an interactive story. "Stories are one of the most fundamental and powerful synthetic experiences available to us" [52, p. 76].

Related to our work are game-based training systems such as the Tactical Language Training System (TactLang) [32], HeartSense [29] [70] and interactive storytelling systems such as Mimesis [91], I-Storytelling [10], FearNot [2], Façade Interactive Drama [40], Oz Project [47] and Magerko's systems [46]. In this project the system scope is limited to the customs officer domain, our expertise and resources available and where possible we draw on existing theories and tools. The fields within the scope of our investigations include: virtual environments; language technology; knowledge acquisition and narrative intelligence. Our main research instrument is experimentation. As a vital precursor to conducting experiments we have designed and built a simulation training system. In conjunction with the experiments we have collected data from participants via observation and surveys.

The prototype systems we have implemented have been developed to the level needed to test the variable/s being explored. The goal is to develop a library of virtual worlds in a number of virtual environments, including games technology using a games engine and a fully immersive virtual reality environment, that can be used for experimentation. We began our studies using a game engine because they are easy to program and the technology is readily accessible for the purposes of testing with experts in the risk domain. We used this experience to better understand the features of the domain and the factors that influence risk. The game engine provided us with 3D graphics, scripted agents and voice and sound. The game engine has been replaced by a VR engine to provide an immersive environment. In the following subsections we describe each of the fields being explored in this research. These fields are brought together in the agent-based system introduced in the next section.

3.1 Desktop VR

VR can range from simple environments presented on a desktop computer to fully immersive multisensory environments experienced through complex head mounted displays and bodysuits. Early in their development, advanced computer graphics were predicted, quite accurately, to make VR a reality for everyone at very low cost and with relative technical ease [50].

A virtual environment is a computer-generated, three-dimensional representation of a setting in which the user of the technology perceives themselves to be and within which interaction takes place; also called a virtual landscape, virtual space or virtual world. A virtual environment is usually rendered onto a two-dimensional output device such as a computer monitor. Examples of virtual environments can be seen in the games of today such as Unreal Tournament 2004 (UT2004) where the worlds are mainly of alien nature, Far Cry which provides the lush greens and blues of forests and beaches and Half Life 2 which mainly consists of building interiors.

To reduce the initial effort and cost we built our first prototype VR training environment using the UT2004 game engine. To provide a training simulation for customs officers we created an Airport Virtual World. The virtual airport, shown in Fig. 1, was created using UnrealEd 3.0, which is the virtual environment editing tool that comes with UT2004. Solely creating an Airport World in UT2004 doesn't allow for management of the story line via techniques such as a Narrative Engine or Game Master Controller. Therefore a modification, we call Risk Management Mod (RMM), to the UT2004 code was created.

Fig. 1. An Airport World Screenshot with chat input field

Our modification acts very similarly to the GameBots modification that began at the University of Southern California's Information Sciences Institute for research in AI and which is used as the basis for projects such as TactLang mentioned previously. We are not using GameBots as it was created for an older version of Unreal that does not include the functionality we required. RMM spawns and allows for control of the NPCs in the Airport World and is described further in section 4.

3.2 Immersive VR

Virtual Reality provides a promising technology to explore visualization and sensory-motor performance. Three-dimensional output devices such as 3D projectors and head-mounted display units provide an immersive sensation for the user. The feeling of actually being within the artificial world is increased when using a three-dimensional output device.

Based on the cinema experience, one could conjecture that as the images become larger and the interactive controls become more sophisticated, the suspension of disbelief and the immersion of the user in the virtual environment increases. Tan et al. [81] conducted a series of experiments to demonstrate physically large displays improve performance on spatial tasks. This may be attributed to large displays immersing users within the problem space and biasing them into using more efficient cognitive strategies. Devices aimed to increase this perception include wrap-around display screens, motion-capture suits, wearable computers, odour generators and haptic controls that let the user feel simulated objects. These more advanced versions of VR are here referred to as True Virtual Reality (TVR).

In spite of advantages of TVR, one should take into account in training that space perception is not simply equivalent to the actual perception. Gooch and Willemsen [24] evaluated space perception in immersive environments and found that perceived distances are 66% of the intended distances. They presented a methodology for quantitatively evaluating spatial perception in a functional, non-photorealistic, stereo, immersive environment. Gamberini [23] found that subjects in immersive virtual conditions performed less efficiently than the control group in object recognition tasks and suggested that human factor concerning motoric and visual interfaces can affect human performance in VE. Therefore, inadequate interfaces can explain when there is a lack of enhancement in immersive visual display. Our aim is to explore how we can address these problems in training simulations.

Building on from the lessons we learnt with RMM in the desktop environment, we developed a virtual reality training system, BOSS (BOrder Security Simulation) for training airport customs officers, using an immersive semi-cylindrical projection system (VISOR: Virtual and Interactive Simulation of Reality) in our Virtual Reality Systems (VRS) Lab to increase the level of immersion.

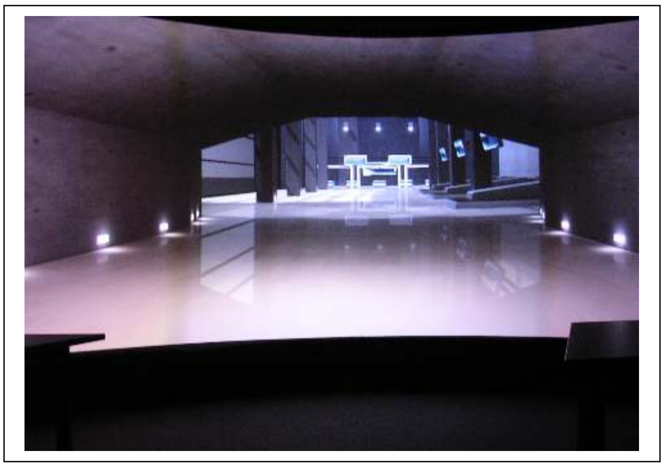

Fig. 2. An airport screenshot in immersive VR

Fig. 3. Preparation for Motion Capture

Study 4, see later, is specifically designed to provide some empirical data to support the value of immersion on learning and specifically test whether screen size affects the level of immersion. The system consists of three projectors which display the virtual world onto a 6m wide semi-cylindrical screen canvas. The user is positioned slightly off centre towards the canvas to allow a 160° field of view (FOV). We used Vizard Virtual Reality Software and a pair of datagloves to interact with the non-player characters (NPCs), developing a gesture based interface. Blender was used to modify the layout of the digital world. The digital world was exported as a Vizard file. We used 3D Studio Max and Softimage|XSI with FBX plug-ins for modelling to create a 3D landscape and an airport model. 3D Studio Max has a built in exporter for .FBX format which MotionBuilder reads. In Motion Builder, we set up the rig of the character and applied the Motion-Capture (mocap) animation onto the character's skeleton, as was shown in Figs 2 and 3. The animation footage is produced by Vizard Virtual Reality software. We are able to generate character animations using models created using the motion capture suit shown in Fig. 3.

The technologies we have used are commercial off the shelf software and commonly used in VR-based simulation systems. However, our application of these technologies to border security are novel. Further, our implementation provides an environment in which to explore (not necessarily in this paper) research questions such as what are the (potential) benefits of the technology on memory, learning transfer and knowledge/skill retention. It must be noted that while there is considerable uptake of VR technology by industry, including the games and defense sectors which are primarily driven by economic or political agendas, respectively, there are still few rigorous studies which clearly identify or measure the actual benefits. For example, the research evidence regarding the value of interactivity and its role with regard to engagement and enjoyment just isn't clear at this stage [83].

We are investing considerable effort into the development of BOSS in order to create a comprehensive, though not complete, and believable environment. We acknowledge that the results of our experiments may be restricted to and limited by the architecture and implementation we have chosen. We nevertheless have sought to find a balance between ecological validity (a realistic, adaptable and therefore complex system) and tight experimental control (very limited number of variables with as simple a design as possible to facilitate data capture and hypothesis testing).

3.3 Language Technology: Paraphrasing and Emotions

In order for agents to be realistic in the context of risk assessment, in many situations their language behaviour will matter. This language behaviour will need to cover a wider variety of expression than is currently the case. In the context of a simulation for training customs officers in an Aiport Virtual World, there is a range of verbal behaviour of interest: for example, the sorts of behaviours found in deception, which might be exhibited by the passengers that the customs agents are assessing. There has been much investigation in the psychological literature about cues to deception in general (see [59] for a meta-study), with some work on language-specific characteristics in particular. In this latter category, Newman et al. [51] have built a system to predict deception in text based on linguistic cues, with an accuracy significantly greater than chance and also greater than human judges; deceptive text "showed lower cognitive complexity, used fewer self-references and other-references, and used more negative emotion words". A second instance is the work of Zhou et al. [92], which also predicts deception in text based on linguistic cues; in the context of real-time textual communication, factors such as informality and affect were found to indicate deception. Capturing these sorts of language behaviours is clearly necessary for a simulation of the sort we describe.

Virtual agents' language behaviour is of two types: language generation (agent to user) and language understanding (user to agent). A primary focus in this project is on the language generation capabilities of the agents; in the above instance of deception, the existing work described is within the language understanding domain. In general, existing natural language generation systems start from an underlying representation of content; their task is to decide between various realisations (e.g. syntactic, such as full sentence versus relative clause; lexical, the choice of vocabulary; or register or attitude, such as formal or informal) in order to express this content. The representations of existing systems (e.g. [33] [75]) allow for some variation depending on speaker intention and so on; however, generation is quite underspecified, not capable of producing the nuances found in speech between humans, for example the use of short clipped sentences and blunt vocabulary to express annoyance, or the use of hesitations, emotional language, or other language behaviours that might be deemed suspicious under risk assessment procedures.

Beginning with an existing natural language generation system, such as described in [33], our task is three-fold:

1. develop a representation that expresses these fine-grained distinctions, both lexical and syntactic;
2. build mechanisms for distinguishing between them under behavioural and contextual constraints, and for automatically acquiring these distinctions; and

3. integrate representations for different aspects of agent behaviour: this may be, for example, through the definition of pairing relations of representations [55].

In developing a representation for fine-grained lexical distinctions, as in the first point above, we are building on the work of Edmonds and Hirst [20], where near-synonyms are divided into four broad classes: denotational, stylistic, expressive, and structural. We are interested in the third of these categories, which describes emotion- or mood-related vocabulary variations, such as the difference between *skinny*, *slender* and *thin* (with the first of these connoting a negative judgement, the second a more positive one, the third more neutral) or between *blunder*, *slip-up* or *error* (ditto). It is the second point above, and in particular the question of automatically acquiring the knowledge of near-synonyms, that is currently the focus of our work. Edmonds [21] defines a statistical model for automatically selecting the best near-synonym for all four types, but its level of accuracy is only a negligible improvement over chance for the seven sets of near-synonyms examined in that work. However, our hypothesis is that a statistical model of the kind used in Edmonds's work can predict expressive near-synonyms, even if not near-synonyms as a whole, and thus is a possible basis for an acquisition system of the type we have described. We describe in Gardiner and Dras [25] a larger-scale experiment than that of Edmonds, and show that in some circumstances expressive near-synonyms can be determined with a statistically significantly higher likelihood. However, adapting the work to the more sophisticated model of near-synonym selection of Inkpen [30], Gardiner and Dras [26] have not repeated the finding, suggesting that the superior detectability (and hence acquirability) of expressive near-synonyms depends on the model used. As a consequence, we are looking at developing a model drawing on a wider range of information such as used in the field of sentiment analysis [82] [57], where texts (such as movie reviews) are classified according to sentiment (such as positive or negative); these suggest a different statistical approach, which we are currently investigating integrating into the near-synonymy work.

3.4 Knowledge Acquisition: Rules and Cases

The capture of knowledge will be relevant to many of our system components and will be stored in one or more knowledge bases. The knowledge bases potentially include production rules about such things as how to detect a risky situation, what language or facial expression is appropriate, which scenario, character or storyline to introduce or when the training session is going to end. Feeding into the voice and sound component of the system is a natural language generator that also accesses a knowledge base (for example, IF agent1 is angry, THEN shout(response)).

One of our key design issues is to build a system where the domain knowledge can be maintained by the domain expert without the need for a knowledge engineer. To provide easy user driven knowledge acquisition (KA) and to avoid the problems associated with verification and validation of traditional rule-based systems as they grow in size [72] we will use the Ripple-Down Rules [13] [35] knowledge acquisition and representation technique. This technique is based on a situated view of knowledge where knowledge is "made-up" to fit the particular context. Knowledge is patched in the local context of a rule that misfires producing decision lists of exceptions. An example RDR is provided in Fig. 4. Context is provided by cases. In our training simulation the current state of the world will be treated as the current case.

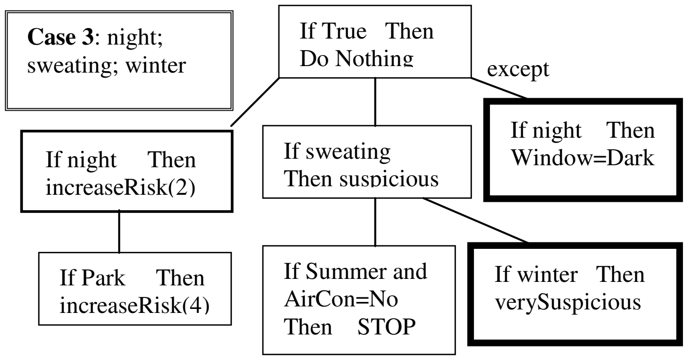

Fig. 4. A Sample RDR knowledge base showing exception structure. Nodes in bold would fire for Case 3.

In accordance with the RDR approach, knowledge acquisition and maintenance will occur when a domain expert is running an existing scenario and finds that they want to introduce a new or alternative situation. For instance, when running the simulation there is some aspect of the environment that is seen to be inappropriate, such as the presence of some piece of furniture, the level of lighting, the tone of voice, etc, the domain expert will be able to interrupt the session and add a rule which captures the current situation, and allows a rule to be added which then changes something in the current situation. Additionally, a rule conclusion may be added which indicates a particular action to take in that context. Such a use of RDR is novel and further research is needed to determine what modifications are needed to the current algorithm and method.

3.5 Narrative intelligence

Narrative is a fundamental principle in human behavior found in everyday communication and part of our culture. At a deeper level narrative acts as a means to structure knowledge [8]. Applying the concept of narrative to the computer is the core idea of the concept of Narrative Intelligence [48]. Narrative Intelligence is not restricted to stories simply displayed on a computer: it consists in structuring the interaction according to narrative principles. From a learning perspective, narrative has two key functions: improving the storage and recall of facts and knowledge on the one hand, provide a more pleasurable and emotional experience, and thus increasing motivation and learning efficiency, on the other hand.

Artificial Intelligence has a central role to play in the implementation of narrative-oriented knowledge representations. This kind of representation has been studied in depth in the 80s, both for story understanding and generation [42] [87]. But new models are needed to handle interactivity.

Several research projects have been conducted recent years in order to structure an interaction in the form of narrative, mostly in the field of interactive entertainment. Such approaches include the Oz Project [86], IDtension [79]

[80], Façade [74] [40], Mimesis [91], Magerko's system [46] and FearNot [84]. The most difficult challenge of a narrative engine is to complement the rationality of individual characters with narrative constraints issued from the global story, with a user oriented narrative view. For example, in the context of a training simulation for risk assessment, if a security officer asks an expert to closely examine a passport, the latter will not give his answer immediately, possibly due to various external reasons, in order to add the element of suspense to the narrative sequence. This example illustrates how a narrative engine improves the mere simulation in terms of emotional engagement.

The narrative component of a training system thus could play a central role in terms of shaping the whole experience. A key challenge is to integrate this component within the agent-based training system, to make it more engaging (see Section 6.2).

4. System Architecture – Bringing the Theory into Practice

For interoperability, extendibility, maintenance and reusability purposes we have taken a modular design approach where each component has separate roles and responsibilities and well defined interfaces to allow other components to access their functionality. Also driving our modular design is the desire to (re)use existing third party components and swap components as required. For example many of the components are provided by third party vendors such as the 3D Modelling and Animation Package (Softimage and 3D Max) and Virtual Reality Physical Interface (Vizard) and voice and sound generator (Festival). More noteworthy, the architecture is seen to be flexible and evolving. As mentioned in the introduction, our architecture includes a number of agents which may or may not be used depending on the level of intelligence required, stage of development of one or more particular components, appropriateness for the given purpose or experiment. We are currently investigating an approach to provide adaptable agents and part of this approach also allows adaptability in the membership of the agents included in our multi-agent system (MAS). Given the fluidity of our architecture, Fig. 5 includes a mix of implementations we have used, combinations we are working on and modules currently under development or proposed. Note that two notions of an agent exist within this architecture and simulation system. An agent can be a self-contained system component, shown as a box e.g the SimMaster Agent. Potentially all boxes in Fig. 5 could be considered agents with varying levels of autonomy, intelligence, pro/re-activity and sociability. Alternatively, we can describe the characters in our simulation system, such as customs officers and passengers, as agents which comprise multiple components (boxes – some of which we call agents) which form the various parts of the character's reasoning (Intelligent Agent Reasoner (IAR)), movement (Character animation), visualization (RT3D Engine), speech (voice and sound generator/NLG), and so on. These character/agents are more complex and sophisticated than the simple agent represented by a box in all aspects, particularly their social and reasoning abilities.

Fig. 5 shows the logical architecture for our agent-based training and simulation system. Grey modules are currently being developed. Boxes are system components which may be implemented as custom built modules or third party software. Rounded boxes are humans. In the top of the diagram, the diagonal dashed lines denote alternative solutions in the modular architecture. Partial physical implementation of these alternatives are discussed below.

Alternative one was used in study 2 (see section 5.2) and includes the modules on the top left ([human]Game Master, SimMaster Agent, character animation, 3D Objects and Worlds and voice and sound generation. Fig. 5 shows RMM, which included the use of the UT2004 Game Engine, as providing all the functionality to handle character animation (in the form of scripted agents), 3D Objects and worlds and voice and sound generation. The SimMaster Agent replaced the interface agent. Alternative 1 uses the human Game Master as the primary source of intelligence throughout the training interaction.

In alternative two, intelligence (i.e. control, flow, storyline, reasoning, conversation, etc) is provided via a narrative intelligence module and was used in study 3 (section 5.3). In this case the Full Story Engine was connected to the Behaviour Engine which communicated with RMM and RMM was connected to the character animation module (UT2004).

The alternative configuration on the top right, to be used in study 4 (section 5.4), replaces the full story engine with a lightweight story engine (Director Agent). In this configuration, intelligence is jointly provided by the IAR which supports the reasoning of our characters and the Director agent which performs reasoning concerning the narrative. Modules on the right of the dashed line are authoring modules in which data, about movement, rules, animations, 3D Objects, scenarios and so on, are captured for use by modules to the left of the dashed line.

The architecture shows a number of agents. As described above, whether an agent is included in a particular implementation will depend on which alternative configuration is to be used (i.e. human game master, full story engine or IAR), the level of sophistication needed for a particular experiment and whether another module or software product provides equivalent or sufficient functionality. The agents we have identified include:

- The Simulation Agent (SimMaster) enables the human Game Master to control all characters in the virtual environment and is only used in alternative one. The SimMaster module, based on the concept of a game master controller used in RPGs, is currently simply an interface which allows a human to send and receive messages from the system via the Behaviour Engine module.

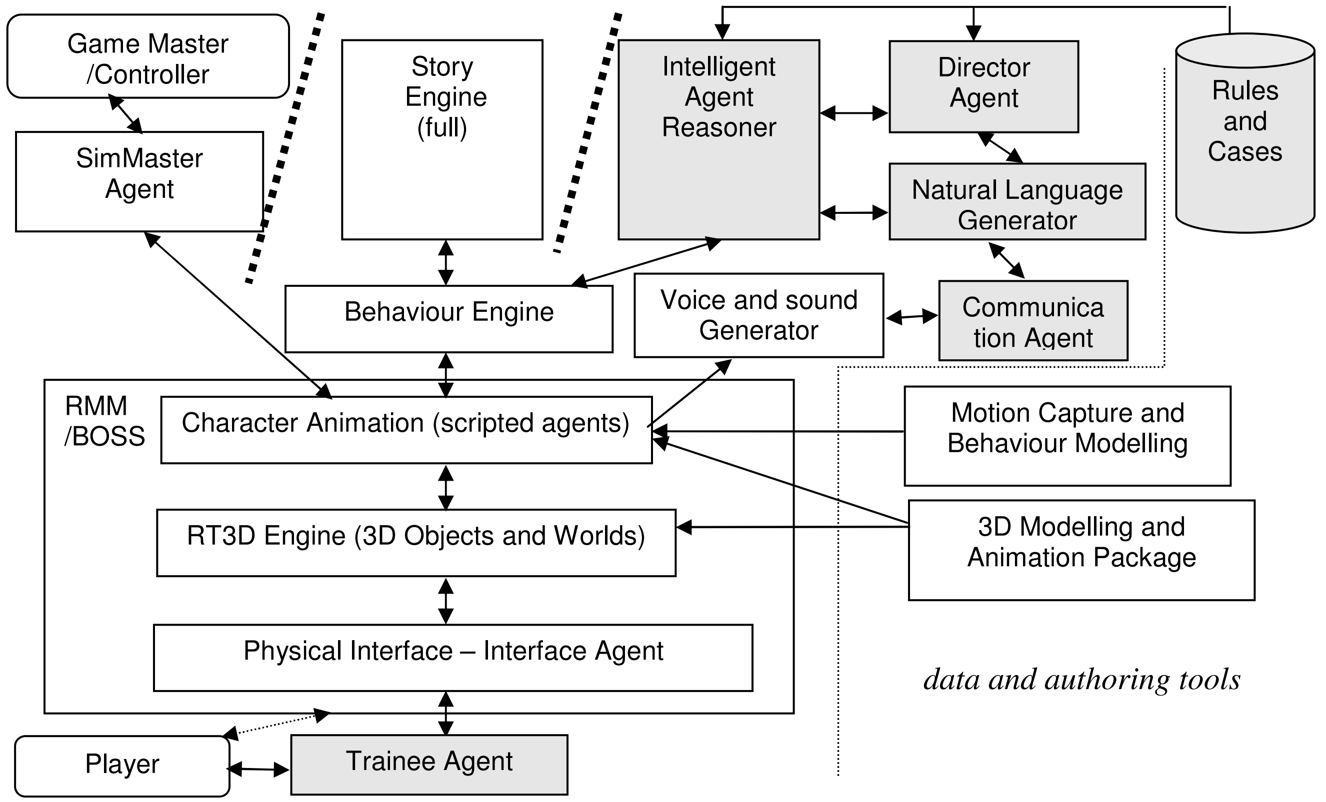

Fig. 5: A logical agent-based training and simulation system architecture

- The Character Animation module includes Scripted Agents which are programmed to initiate a negotiation with the Trainee whether to terminate the process, slow down, or continue, and initiate an action at the next opportune time, depending on the commands of the Trainee Agent and SimMaster (if alternative one).
- The Trainee Agent represents the human trainee using the system in either a local or remote location. The Trainee Agent negotiates with the Scripted Agents during potential risk situations. The trainee agent updates the user profile of the system and sends messages to the Simulation Agent, Interface Agent and Communication Agent. The Trainee Agent monitors the immediate environment, making sure that the Trainee is properly trained regarding risk situations in a potential crime zone. The Trainee Agent is still being developed and our implementations and studies to date have not involved modeling or managing the trainee's interaction via an agent. Thus the dashed line is a temporary direct communication link between the human Trainee and user interface.
- The Interface Agent proposes an adaptive and intuitive gesture/mouse/keyboard-based interface using the profile of the trainee agent. The user may communicate with the system using datagloves, head mounted display, semi-cylindrical projection system, stereoscopic goggles, keyboard, mouse or any other interface available.
- The Communication Agent is responsible for the speech-based communication with the scripted agents using a natural language generator and a speech synthesiser. Currently a text to speech (tts) generator (Festival) provides one way communication (output only) using the text provided from the character animation. In the future the Natural Language Generator module will feed input into the Communication Agent who will use the appropriate intonation, inflection, pitch and expression (including voice and potentially gesture and facial expression). Further ahead we would like to incorporate speech recognition capabilities into this agent.
- The full story engine is able to decide about all actions of characters, according to the user's action. In the current implementation, it does not need the IAR and can plug directly into the Behavior Engine. An experiment with such an engine is reported in the next section.
- The director agent interacts with the IAR in order to drive the experience towards a narrative sequence. Compared to the story engine, it does not include the whole simulation of character actions but it interacts with the intelligent reasoner in order to provide complementary guidance in terms of narrative constraints.

The Behavioural Engine (BE) is a module for transforming high level actions calculated by the Story Engine into low level animation commands for the Unreal Tournament Game Engine and combine to form the narrative engine. These external client programs make the decisions related to the actions of the NPCs such as walk, run, turn and talk. The natural language generator is currently under development and when complete will allow generation of paraphrased sentences according to the given context which will be passed to it. The IAR will be developed to add intelligence to the system and allow the knowledge to be acquired incrementally and by the trainer as described briefly in section 3.4. The BOSS VR prototype (alternative three) being developed will include all shaded modules shown in Fig. 5.

5. Evaluation Studies

Data collected in a typical laboratory setting is often difficult to extrapolate to real-world situations outside of the sterile or artificial laboratory. Alternatively, the ability to control variables in a real-life setting can be even more problematic. One key application of virtual environment technology is the ability to design and conduct controlled experiments with the potential for high ecological validity. We want to both exploit and test this benefit through the study of virtual environment technology and its value as a training tool using a virtual environment. This is a general goal of all the studies described in this section. More specifically we are interested in examining the key features of virtual reality systems which are: visualization, interactivity and immersion [37]. These three features can be seen a part of a continuum as shown in Fig. 6 where each feature builds on the previous one to allow the user to see (visualize), do (interact) and experience (immerse).

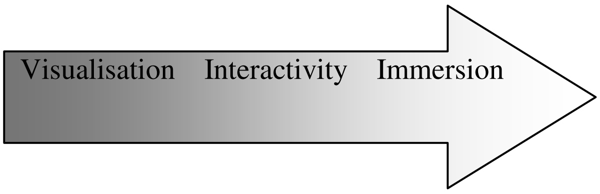

Fig. 6. A Continuum of VR System Key Features

We are conducting a number of studies into the role and effect of each of these factors on the learning experience, firstly providing visualization, for example of the training material, followed by visualization plus the ability to interact with the material and finally full immersion involving visualization, interactivity and a sense of "being situated" in the training scenario.

Following this line of reasoning, we have designed a number of trials the first of which compares a video of a training scenario with an alternative visual representation in the form of a game demonstration. The video and demonstration are non-interactive. The focus in this first study was on the visualization. Two studies were conducted to consider the issue of interactivity. One trial (study 2) compared the game demonstration with an interactive version of the same game and training scenarios. A Wizard of Oz approach was taken which used a human Game Master, similar to those used in Role-Playing Games (RPGs) to respond to the user and control the interaction. Study 3 sought to provide an "artificial intelligence" using automatic narrative management to control the interaction. The final trial (study 4) is multi-faceted and in addition to allowing the user to visualize and interact with the training scenario, we alternate a number of factors to explore the level of immersion experienced by the user in response to the combination of factors. The following four subsections describe the four studies.

5.1 Study 1 - Visualisation

As we intended at the start of our project to use a computer-generated game environment, we wanted to validate if such a visualisation was appropriate for a training simulation. Perhaps participants would switch off or be distracted by the lack of graphic realism. To explore the goal of comparing a real-life visualisation with a computer-generated visualisation we sought to test whether watching a video recording of a risk-based scenario involving humans produced better, worse or the same results as a simulation of a similar scenario created in a game engine with animated characters. The video clip was taken from the ATN Channel 7 reality TV program "Border Security" which involved real passengers at Sydney and Melbourne airports being questioned/interviewed by airport customs officers, see Fig. 7. The agents were scripted in our game demonstration based on a similar scenario from that TV program, see Fig. 8.

Fig. 7. Screenshot from ATN 7 Border Security Video

Fig. 8. Screenshot from Game Demonstration

There was no interactivity via the video or game demonstration. 74 third year Computer Graphics students were involved in the study. After watching the video they completed a survey with nine questions about the scenario. Likewise, after watching the game demonstration they completed another survey with nine questions of similar difficulty but related to the second scenario. The questions sought to compare the effect of the media on the participants' attention, memory and reasoning.

Despite the lack of graphical realism and sophistication of our game demonstration, the accuracy of answers and the level of detail recalled were almost identical for both situations. The results encouraged us to believe that while the graphics in the game demonstration were very dissimilar to the realism of the film, the participants were still able to pick up the key details and draw reasonable conclusions regarding the scenario. More detail on the study is provided in [62]. A summary of the participants impressions of the system and how it compared with the video representation are given in Table 1.

Table 1: Participants positive and negative responses to the game demonstration visualization.

Positive Responses	Negative Responses
funny (2)	boring
free to make mistakes	not realistic (4)
potential to recreate a lot of scenarios (5)	no expressions other than voice (2)
it improves the understanding and absorption process: images are better than slides (2)	probably more expensive and time consuming to create compared to actors with cameras
no harsh after effects of security breach in the case of real life training	possibly would not cover all scenarios
rather than just purely vocal (from overseas 2 students)	not too dissimilar from reading a case study
easy to understand the problem (3)	not clear (2)
it is more clear compared to the Video demo (2)	unrealistic movement of characters (2)
able to try new things	scenario was too easy (3).
practice time is not limited	
cost-effective (3)	
text is helpful	
understanding of the atmosphere.	

A number of specific and general comments on how to improve the system were given by the participants, but overwhelmingly there was a request for interactivity and greater realism. On the realism side this study showed that the lack of realism did not impair attention or memory and supports studies such as [4] which have shown that humans are able to engage with unrealistic characters and are willing to suspend their beliefs concerning reality in such situations. What was not evaluated was the value of interactivity for learning. This is what study 2 sought to test.

5.2 Study 2 - Interactivity

As the participants in our first study confirmed, interactivity is commonly believed to enhance learning and entertainment. In the second study we sought to test whether allowing participants to make decisions, ask questions, and respond to answers would make the learning material more memorable and allow the learning principles to be better transferred to similar training situations.

In our study the only variable we wished to change was whether interactivity was possible or not. Each of the 17 volunteers experienced the control condition, a training/game demonstration involving one of two possible scenarios, and an interactive session in which they "played" the same game they had watched with the alternate scenario. The order of scenarios and the order in which one experienced the interactive game or game demo were also swapped, resulting in four randomly assigned test groups. Following the completion of each scenario, the subject was asked to answer a number of questions to test whether they had paid attention, what they had remembered, what they had learnt about being a customs officer and to answer how they would respond to four new situations that had some similarities with the scenarios they had been exposed to. We determined which of the responses were actually correct given what had transpired in the demo and which we sought to recreate in the interactive session. This meant that we were also looking at how many right and wrong questions were given by an individual and the space of correct answers.

Given the small sample size, number of questions, range of answers, need for qualitative interpretation and the four groups involving different scenarios and tasks and orderings, we are not able to offer quantitative results or definitive claims. Nevertheless, the results indicate that groups performed better after the demonstration, particularly if the demonstration was performed first, that there was still a greater preference for the interactive session and prevailing belief that interactivity is better than none. The goal of interactivity in the educational setting should be to enhance the experience and achieve greater engagement leading to greater learning. However, this study does not indicate that greater learning had been achieved when interactivity was involved while supporting that people will, in general, prefer to interactively participate when given the choice. However, the effort in providing interactivity, even in this study was far greater than providing the demonstrations. Given that the results in general were slightly worse and the time and development costs greater to provide interactivity, one has to reconsider its value and appropriate role.

In support of interactivity, it appears that interactivity provided the hands-on experience useful for learning what to ask and how to behave. It is possible that our novice population were so unfamiliar with the domain that they did not have enough basic knowledge to get the best from the experience. More detail and discussion of this study can be found in [63]. We plan in the next few months to repeat our study with Macquarie University Security Officers who would be more familiar with the security domain. We anticipate better results for interactivity, if the technical aspects and unfamiliarity of dealing with the game system is not a hindrance in this group of users who we expect to be less computer and game savvy. In a nutshell, the study reveals that interactivity should be used in conjunction with more traditional methods of learning such as reading and instruction and used to support the learning of practical tasks and transfer of tacit knowledge. The key point is that in these training situations there is not one right way of doing something. This would suggest that the power of simulation is not for transferring declarative knowledge but to provide a practice environment for already acquired knowledge (procedural or declarative).

5.3 Study 3 – Automatic narrative management

We implemented a first version of the architecture below with a full story engine called IDtension [78], a Behavior Engine developed for the project and RMM, the Unreal Tournament Mod for risk management. The technical implementation has been described elsewhere [80]. We want to discuss here about the effective use of this first architecture for training.

IDtension is a highly generative story engine, in the sense that, contrary to Façade for example [74], it does not rely on a predefined set of story events. Neither does it claim to be based on the emergence of narrative from the simulation of characters, because narrative emergence is quite difficult to implement practically. Rather, IDtension is based on a set of elementary and abstract units like goals, tasks and obstacles. These units are dynamically combined to create actions and events in the narrative. Through this decomposition-recomposition process, the system allows the user to choose among a large set of possibilities and feel a sense of agency in the virtual world [49]. For example, if a user is trained to be a security officer facing a passenger in an airport, if s/he wants to check the exactitude of some information, s/he is given a panel of options. S/he can choose one of these options, or several, either at the same time (parallel investigation) or successively, in any order and whenever s/he wants. The narrative engine is then responsible for responding to these various investigations, in a timely and narratively interesting manner, see Fig. 9.

Fig. 9. Narrative Engine with RMM

A key feature of such a narrative engine is the model of the user. In order to be able to recompose dynamically a narrative sequence, the system must estimate the impact of each possible action or event to the user. A few user models for Interactive Narrative have been proposed so far (e.g. [78] [86]). In the first simulations, we used the standard user model, even if we intended to develop a user model customized for the learning domain.

A simple scenario was implemented within the IDtension framework. However, we quickly found it difficult to adapt our risk simulation scenario to the IDtension formalism. IDtension was offering both too much and not enough possibilities. Indeed, on the one hand IDtension was giving the possibility to inform any character about any other character's goal or performed tasks, a great feature in an entertainment context where multiple plots are interwoven, but not really relevant in this context, where the goals of characters are rather obvious, and everybody is in the same space. On the other hand, characters' psychology is rather simple in IDtension, because what finally counts in drama is what people do (drama means action), while in this project we are trying to make trainers aware of the psychology, to some extent, of the situation and passenger. Given these difficulties, we did not conduct a user evaluation of the architecture with the implemented risk scenario. Rather, we are now focusing our research on redesigning the narrative management, in order to both include the Intelligent Agent Reasoner and simplify the narrative management (section 6.2).

5.4 Study 4 - Immersion

Study 2 supported the view that:

> "the mere inclusion of user choice in media does not automatically make engaging events: interactive entertainment programs are not necessarily more entertaining. In the same vein, educational programs do not necessarily teach more effectively and deeply … The creators' challenges are the same as they have [sic] always been with the additional challenge of interactivity. The same careful design and artistic inspiration will be necessary to make the processes of interactivity themselves key artistic or conceptual elements. [88, p.11].

Clearly our challenge is to carefully design a system which recreates a training environment containing the factors most relevant and useful for successful learning.

As part of this system the visualization (appearance of the content) and level of interactivity would need to be appropriately designed. Further we wanted to test the impact of immersion on learning using virtual reality simulations. To this end we installed VISOR, an immersive projection system, as seen in Figs 10 and 11.

Our current experiment concerns the use of three airport scenarios: drugs, food and passport, of similar complexity and length which will be shown on a single screen, three screen configuration and projected in the CAVE. Using a latin squares design, 36 participants will experience each scenario and each output media. We will measure their tendency to become immersed, prior domain knowledge, post domain knowledge, motion sickness in the CAVE and level of presence or *flow* [15] immediately following each scenario. Douglas and Hargadon [19] describe flow as "a state in which readers are both immersed and engaged". Surveys will be the instrument used to measure what has been remembered and to test the level to which participants perceive themselves to have become so absorbed in the environment that they lost track of time and self-awareness.

Fig. 10. Trainee in VISOR using RMM

Fig. 11. Stereo Airport model connected to BOSS

Fig. 12. VR Lab showing the three screen configuration in the foreground and VISOR in the background

Biometrics such as heart rate and skin conductance will also be measured to crossvalidate the surveys regarding the participants perceived level of immersion.

In the mid to longer term, BOSS offers a prototype platform for building, integrating and testing for further developing our ideas. This includes: exploring research into gait recognition as a biometric key for terrorists [34] by integrating spatial navigation and motion tracking into BOSS; testing whether participants are able to detect suspicious situations based on the language used, using alternate paraphrases of similar scenarios (section 3.3).

6. Discussion

In this project we endeavour to bring together a number of research areas as introduced in section 3. Our approach in each of these areas are discussed further in the following subsections and compared with related work. We also include the limitations of our current work.

6.1 Virtual Reality and Learning

The capacity for allowing learners to display and interact with information and the environment is seen by some to be VR's greatest advantage [1]. VR is also a very valuable alternate medium for instruction and practice when the actual training is hazardous to learners, instructors, equipment, or the environment [58] [59]. This advantage of the technology has been cited by developers and researchers from such diverse fields as firefighting, anti-terrorism training, nuclear decommissioning, crane driving and safety, aircraft inspection and maintenance, automotive spray painting, and pedestrian safety for children [1].

There are a number of immersive systems installed for training of military personnel. Delta Force 2 game, for example, helps familiarize soldiers with the military's experimental Land Warrior system [38].

The Mission Rehearsal Exercise System (MRE) [77] is supported by the US Army in order to develop an immersive learning environment where the participants experience the sights, sounds, and circumstances, as they encounter real-world scenarios. Its aim is to build intelligent agents that are able to respond and adapt to their environment in natural and believable ways, creating a movie-like realism.

The SEER mini-dome simulator, with a radius of 1.5 m, provides full immersion with constant eye relief over the entirely spherical surface to enable effective training of fast jet pilots using Typhoon Emulated Deployable Cockpit Trainer (EDCT) in the RAF's 29 Squadron Operational Conversion Unit (OCU) [3].

Although, these systems have been in use for half a decade, there are no reports on their effects on training military personnel. Therefore there is a need to report on these issues and we aim at addressing this need.

Some general limitations and problems have been noted [39]:

- Simulations cannot react to unexpected 'sub-goals' which learners may develop during the process.
- Simulations may be more time consuming than alternative learning activities.
- Learners may become wrapped up in the simulated activity (especially if game based) and lose sight of its objectives.
- Learners will have varying experiences and may not complete all components.
- Success of the simulation will depend heavily on the design.

- Negative biases may exist in the design, and undesirable attitude changes may be produced as a result.
- No widely accepted criteria have been established for decisive evaluation of simulations.

Simulations to date are limited in their language technologies, agent-based design issues are many, and agent intelligence is limited, providing problems with realism and autonomous agents. This problem can however be overcome with live instructors or by making simulations team-based. For example, at the time of the trials in study 2, our narrative engine was not sufficiently sophisticated to provide robust interaction and thus we used a human *game master* to provide intelligent interaction capabilities with participants in a wizard of Oz style interface. The game master was able to answer the questions of the participant and also drop hints such as ask if the trainee officer wanted particular help, such as searching the passenger's body or luggage.

6.2 Beyond simulation: narrative and pedagogy

Our initial experiment with the narrative engine has shown that the project has specific needs in terms of knowledge representation and authoring. To address these needs, the Director Agent should be managed in conjunction with the Intelligent Agent Reasoner. A promising approach is to implement the Director Agent with the same kind of formalism used in the Intelligent Agent Reasoner. This will enable the use of the iterative methodology for knowledge acquisition described in Section 3.4.

The key research issue is how the rules of the Intelligent Agent Reasoner and the rules of the Director Agent interact with each other. This interaction is not trivial. There exist partial solutions in the literature. The first one consists in letting the Director Agent manage the global structure of the story, in terms of a linear or multi-linear sequence of scenes, while agents and the interactions with them intervene within scenes [73] [46] [18]. This solution is however limited because what happens within a scene is not narratively driven and does not influence significantly what happens later (because the story is more or less predefined). The second solution consists of letting the agents act and wait for the story to emerge from the interaction. However, story usually does not emerge. Agents must be designed specifically to favor emergence, and one does not know how (but see [45] for an interesting attempt).

In order to better manage the interaction between the Agent Reasoner and the Director Agent, our idea is that no module is controlling the other, but a negotiation process has to take place, as sketched in [79]**.** Two negotiation schemes are proposed:

- The Agent Reasoner provides the Director Agent with a list of suitable actions and the latter selects the most interesting one, according to its own set of criteria.

- Director Agent asks the Agent Reasoner to execute a desired action if a justification for this act can be found.

This second solution means that the agents are not only characters but also actors, in the sense that they are able to act according to constraints outside the fictional world. This kind of idea has been partially implemented in [65].

At this stage, we leave open the type of narrative management, in order to encourage a progressive authoring approach. Simple rule management will be implemented and tested first before trying more advanced drama management, allowing more variation in the story. Simple management consists of a fixed sequencing of scenes [73]. Intermediate management could be based on the sequencing of generic events [46] [18], while more advanced system will implement higher level constraints based on narrative perception [78] [12].

Pedagogical constraints on the simulation should also be implemented in the Director Agent. This means that the Director Agent will be able to promote some events in order to fulfill both narrative and pedagogical constraints [66].

6.3 Language Technology

There are a number of systems which allow the integration of speech into agents that can be used in simulations. Several systems allow this integration in principle. In general, however, none of these incorporate fine-grained distinctions in the language component, and all of the language knowledge must be hand-developed and hand-coded. For example, the Jack project [54] which has typically been used for military simulations covering specific situations such as behaviour at checkpoints, uses as its internal representation Synchronous Tree Adjoining Grammar, which for this system pairs a grammar for agent actions and a grammar for language. The grammar covers a subset of English, but does not concern itself only with the sort of broad language behaviours an agent would need at a checkpoint, rather than more fine-grained nuances, and is hand-coded.

Another kind of agent combining language and action is the talking head RUTH [75]. The facial expressions of RUTH can be set, and a language generation component plugged in with annotations that allow synchronization with the expressions. Possible language generation components range from canned text, to a simple Eliza-style system (with rule-based patterns and responses, and incorporating a limited ability to remember previous elements of conversation), to the more sophisticated language generation system SPUD [76] which incorporates semantics and discourse aspects of language. However, again, fine-grained distinctions are not part of any of these, although they can be incorporated; and currently the linguistic knowledge must be hand-developed.

There are a number of similar agents focusing on different aspects, such as REA [9] where the agent is a model real estate agent in a more complex environment; and Greta [67], where the focus is more on animation of the talking head. However, none of these focus on emotion through fine-grained linguistic distinctions as we do here.

6.4 KA for risk assessment simulations and management

Knowledge based systems have been employed in many risk management systems concerning the environment and engineering [5], project management related risks [53], bank loan risk assessment [89] and in the financial sector for the modeling of financial decision problems regarding the assessment of corporate performance and viability [93]. KBS are useful for risk assessment, which can be seen as a type of "whatif" analysis as they provide a way of structuring the dependencies between the different variables required for decision making.

A technique to handling knowledge and provide system intelligence which has been commonly used by the agent and autonomous multi-agent systems community is the Belief-Desire-Intention (BDI) model of human cognition [7] formalized by [61]. Such approaches have been used for management of risk situations related to disaster relief [31]. In this work they extend BDI to handle multiple events and perform situation analysis. Of potential interest to our work on training for risk assessment is their approach to situation identification and assessment.

Combining KBS, MAS and risk assessment is the work of Lorenz et al. [44] who take advantage of the ability of distributed agents to independently reason and take action as required and also when needed work together using a number of individual and/or common knowledge bases to perform joint decision making. In the approach, each agent manages its own fraction of the knowledge base containing the knowledge needed by the entire system for risk management. Similarly, as outlined before our knowledge base will contain knowledge needed by multiple types of agents with different goals and capabilities.

We take knowledge to include an everchanging combination of framed experiences, values, contextual information and human insight that can be stored in documents, repositories, processes and practices to allow new situations and information to be evaluated and integrated [16]. One way of capturing past experiences and applying them to new situations is the use of case-based reasoning (CBR). CBR systems have been offered for many trouble shooting situations, such as the help desk [11] and even as the basis for knowledge management systems to aid with disaster response and management [55].

The approach that we suggest to manage knowledge as introduced in section 3.4 was the ripple down rules technique which is a hybrid CBR and rule-based system which seeks to gain the benefits of both approaches while avoiding the pitfalls such as the need for manual and tedious indexing of cases in CBR systems or lack of context or groundedness in rule-based systems. Knowledge can be acquired in a bottom-up case-driven or top-down rule-driven manner. The rules effectively become the index by which the cases are linked and retrieved. The cases motivate knowledge acquisition by providing a failure-driven technique which requires new knowledge to be added, or past knowledge to be overridden when a new situation arises that is not correctly classified by the current knowledge in the system.

7. Conclusions

Simulation systems are gaining popularity in many domains for the purposes of education, training and even entertainment. A number of researchers have sought to characterize these types of systems and draw conclusions regarding the current state of the art and future of these systems. We note, however, that while the features, characteristics and definitions allow some comparison and evaluation to be made, it is often difficult to apply or identify a particular system as belonging to a certain category or the extent to which a certain feature may be offered. For example, the system we have presented falls into Farber's [22] category of experimental simulation as it provides a form of problem-based learning but is also a symbolic representation of the environment using scenarios to which the user must respond and to which the system will provide feedback. Similarly using Boyle's [6] categories our first study using a game demonstration was a *passive simulation* but the second and third studies can be seen to provide *exploration* and *task-based* simulations. Following Davis [17] and Prensky [60] BOSS offers a *virtual* and *constructive* simulation.

It is clear that the VR and games field is still maturing and that theory is lagging behind practice which is being primarily driven by industry's anticipation of users' needs and wants. Our studies to date suggest that, for this particular training application and implementation, computer game graphics do not detract from learner performance, but that interactivity detracted from learner performance (although interactivity was preferred). Among other planned studies, we intend to explore further the value of VR environments, in various forms such as desktop and cave, against more traditional methods such as a videos or training manuals. In this way, BOSS is providing a platform to apply and extend a number of existing theories from computer science and artificial intelligence to training simulations to add greater rigour to the field while also addressing many of the open theoretical, technical and implementation issues.

Acknowledgements

This project is sponsored by the Australian Research Council (ARC): ARC Discovery Grant (DP0558852). Special thanks to Iwan Kartiko for the production of 3D models and digital animations, Jason Barles on RMM, John Porte on various modules of BOSS and Anders Tychsen for his assistance with study 2 and related work on RPGs. Thanks to anonymous reviewers for comments and some valuable observations that have been incorporated.

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