The Potential for Intelligent Software Agents in Defence Simulation[1]

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1 Introduction

Our objective is to describe the application of intelligent software agents to military simulation. Defence simulation is used to support procurement, force development, evaluation of C3 structures and for training. In all these applications it is necessary to model both individual human reasoning and team behaviour. We describe the intelligent agent and outline the current 'state of the art' in agent technology, including the modelling of team behaviour and agents that can learn. We cover a number of recent and current intelligent agent applications that are demonstrating the potential for agents to effectively represent human reasoning and teams in C3 models.

The term *agent* is widely used to describe a range of software varying in capability from the procedural 'wizards' found in popular desktop applications, to information agents for information search and retrieval, and to intelligent agents capable of simple rational reasoning. The intelligent agent as described here is an autonomous piece of software, which has explicit goals or *desires* to achieve, and is pre-programmed with plans or behaviours to achieve these goals under varying circumstances. Set to work, the agent pursues its given goals adopting the appropriate plans, or *intentions*, according to its current *beliefs* about the state of the world, so as to perform the role it has been given. Such an intelligent agent is generally referred to as a Belief-Desire-Intention (BDI) agent.

Under the BDI model, agents may be given 'pre-compiled' behaviours, or they may plan or learn new plans at execution time. Giving BDI agents pre-compiled plans is a method for ensuring predictable behaviour under critical operational conditions, and for ensuring performance.

BDI agents are highly suited to the development of time and mission critical systems, as the BDI approach provides for the verification and validation of the model. The agent's goals may include keeping the human users informed of what the agent is trying to achieve, what its current intentions are, and how far it has got.

The ability of intelligent agents to perform simple tasks autonomously has aroused much interest in the potential military applications. Key characteristics of intelligent agents that make them attractive are:

- autonomy;
- high-level representation of behaviour - easy to define command and control architectures;
- flexible behaviour, combination of pro-activity and reactivity;
- real-time performance;
- suitability for distributed applications; and
- ability to work cooperatively in teams.

The development of intelligent agents has evolved from the early Artificial Intelligence research into the development of autonomous mission critical software technologies. Initial concepts for intelligent agents were explored at SRI International by Georgeff and Lansky (1986) in the mid-1980's and later formalised by Rao and Georgeff (1990) in the early 1990's. An early implementation was the development of the LISP-based Procedural Reasoning System (PRS). The SOAR system was also developed in the USA at this time and has since been used by ISI at the University of Southern California for prototype applications.

Research into distributed real-time AI systems and agent architectures at the Australian Artificial Intelligence Institute (AAII) in the early 1990's by Rao, Georgeff and others (Wooldridge & Rao, 1997) resulted in the development of second-generation dMARS C++ multi-agent system. Parallel development by Ingrand in France led to the C-PRS single agent system (Ingrand et al, 1996).

Current developments include two JAVA-based agent developments: the BT

Laboratories, UK ZEUS agents toolkit (Nwana et al, 1998); and the JAM system from IRS, USA. A JAVA based commercial product called JACK Intelligent Agent™ has also been released, by Agent Oriented Software in Australia.

2 Defence Applications

Historically computer simulation has been used for the evaluation of acquisitions and of force development options. Modelling and simulation for this purpose is becoming increasingly complex as multi-role, multi-platform and multi-system aspects are taken into consideration. The complexity of this task is further increased by the difficulty in modelling human decision-making with sufficient fidelity using conventional software approaches. Current implementations of Computer Generated Forces, such as ModSAF, have proven to be very useful, but do not model human reasoning and cannot easily model team behaviour. Early applications of intelligent agents in simulations to represent operational military reasoning have proved highly effective. This success comes from the capability of agents to represent individual reasoning and from the architectural advantages of that representation to the user due to the ease of setting up and modifying operational reasoning or tactics for various studies. In addition, the BDI class of agents extends the modelling of reasoning to explicitly model the communications and coordination of joint activities required for team behaviour.

The emphasis on timely, accurate information in modern warfare, and the availability of modern communications, have led to the development of increasingly complex command and control systems. It is important to understand the behaviour of these C3 systems under a variety of circumstances. However, as they are difficult to analyse manually, advanced modelling and simulation tools for C3 systems development are required. The challenge in C3 systems is to model the reasoning associated with different roles in the command and control hierarchy. Intelligent agents can represent the reasoning and command capabilities associated with their assigned roles in the hierarchy, allowing different command and control strategies to be quickly evaluated under varying circumstances. This power comes from the suitability of the BDI architecture for representing individual and team objectives, and roles.

The contemporary trend towards the integration of multi-role forces, together with the high cost of live exercises, has required the development of more realistic training environments. However, these synthetic environments have not been able to model the behaviour of the humans involved, other than in a very simple manner. In particular, they have not modelled team behaviour with the result that trainees quickly learn the range of simulated behaviours. Rather than practising their military skills, they learn to predict the training system's response. Intelligent agents allow the Computer Generated Forces in training systems to behave in a more human-like manner, with a much richer set of behaviours including team responses and dynamic role re-allocation. The result is a more effective training environment with realistic tactical behaviour represented, whilst avoiding the expense of having humans involved to provide this.

3 Applications of the BDI Intelligent Agent Concept

In parallel with the further development and formalisation of the BDI architecture, a number of multi-agent applications were developed using PRS and dMARS, including:

- The OASIS air traffic management system prototype by Lucas, Ljungberg and others for Airservices Australia (Lucas 1997, Ljungberg & Lucas 1992, Lucas et al 1995).
- The SWARMM air mission simulation system by Tidhar, Lucas, Rao, Appla, Heinze and others for DSTO Australia (Tidhar et al 1995, Rao et al 1993, Lucas et al 1992).

- The IRTNMS network management system prototype by Rao, Lucas and others (Rao & Georgeff 1990) for Telstra (formerly Telecom Australia).
- The RCS fault diagnosis system demonstrator by Georgeff, Hodgson, Kinny and Rönnquist for NASA.

This number and variety of applications has established a sound R&D capability in multi-agent systems in Australia. In particular, the success of the SWARMM system encouraged DSTO to proceed with further multi-agent simulation developments:

- The BattleModel developed by Air Operations Division (Lloyd, Appla, Heinze, Tidhar and others) as the basis for future capability modelling in the AEW&C Support Facility for an Australian AEW&C aircraft (Project Wedgetail).
- Land Operations Division's CAEN/dMARS demonstrator (Rönnquist & Gaertner), to illustrate the potential of agent in land operations simulation.

4 Modelling Teams

Team work requires both coordination and shared goals. Cohen and Levesque (1991) highlight the distinction between coordination and teamwork with the example of the distinction between driving in traffic and being part of a convoy. Both situations require coordination, in the first case with traffic signals and road rules. The second requires teamwork; that is, collaboration between the vehicles. A team has shared goals and intentions.

The situation we need to model in support of combined military operations is teams of teams (friendly, neutral and hostile forces) acting in concert in a competitive environment. Communications and coordination have been found to be serious issues in the provision of artificial agents in man-in-the-loop simulation (Tambe, 1995). The emerging view is that intentionality, and team behaviour needs to be built into the team architecture from the ground up. Grosz (1996) summarises it as: “the capabilities for teamwork cannot be patched on but must be designed in from the start”.

Tambe (1997) points out that agent architectures have so far focussed on individual agent’s flexible behaviours. However, building multi-agent systems by fitting agents with pre-computed coordination plans will not succeed as these plans are inherently inflexible, fail to anticipate particular situations, and their domain dependence means they are difficult to re-use. In Tambe’s implementation of STEAM, the focus is on a general model of teamwork.

Similarly, the focus in knowledge-based systems development, and in work and task analysis is also on the individual rather than the team.

The OASIS and IRTNMS systems illustrated that BDI agent architectures provide a powerful means for implementing complex, distributed systems using multiple BDI agents. The SWARMM air mission model was the first application to introduce BDI agents in teams: the success of SWARMM has been followed by more ambitious C3 agent models in the BattleModel, CAEN/dMARS demonstrator and current DSTO C3 models for land and air/sea surveillance.

Current Australian research in teams is directed towards BDI agents in command and control (Tidhar, Rao & Sonnenberg 1998).

5 Intention Recognition

The success of the SWARMM system stimulated interest in how to determine the opponents' intentions, and resulted in early research into the Recognition of Intentions by Rao (1994) in the early 1990's, followed by application to military situation awareness by Rao and Murray (1994). Rao et al have provided the theoretical structure for agents which recognise the intents of agents other than those in the agent's own team structure. Concept demonstration software has been written by Tidhar and Busetta (1996) of a Belief, Desire & Intention model for Recognition of Intentions (BDI-R) system for air combat: this remains to be developed to a robust scaled up system.

For the recognition of an opponent's intentions, the issue is essentially the recognition of plans whilst they are in execution. The problem is harder than identifying an action upon its completion: to be of practical assistance, an agent needs to know what is happening *before that event is over*.

An approach has been found in machine vision, where Goss and Pearce (1997) have demonstrated a method for learning action plans from spatio-temporal data which describe action plans of agent/entities in a virtual environment in flight simulator (Pearce et al. 1998, 1997). This runs in real time and announces attributed plan segments *whilst* the pilot is executing them. It provides a demonstration of the feasibility of real-time recognition (Pearce et al. to be published).

6 Current Australian Research and Development in BDI Agents

Current Australian agent research is centred around The University of Melbourne's Intelligent Agent Laboratory. In addition to the activities described above, extending team behaviour and developing a learning capability, it includes:

- inspection of multi-agent systems (Rönnquist & Low 1997);
- transaction-based multi-agent systems (Busetta & Kotagiri 1998); and
- information and internet agents (Loke et al 1998).

7 Requirement for an Agent Platform for Simulation Development and Re-Engineering

Experience with the BDI applications described above showed the necessity for the development of an agent kernel which would be flexible enough to allow different types of agents whilst being easy to integrate with existing simulation architectures. The kernel would have to be easily portable between different hardware and operating systems. Furthermore, the system must easily accommodate the introduction of new agent capability, such as joint intentions and recognition of intentions.

One result has been the development of a new multi-agent system called JACK Intelligent Agents ("JACK"). JACK is a JAVA-based intelligent agent kernel, developed as a product by Agent Oriented Software based upon the company's R&D into software agent technologies.

JACK is currently being used in the development of DSTO Land Operations Division's Land Situation Awareness (LSAP) system, designed as an advanced decision support environment for operational commanders. JACK is being used to manage the information collection plan in support of enemy Courses of Action analysis. JACK is also currently being considered by DSTO for modelling and simulation of the C3 aspects of wide area sea/air surveillance, under the Integrated Surveillance Assessment Tool project.

8 Conclusions

The intelligent agent is a valuable software concept which has the potential to be more widely used in defence command decision modelling as it overcomes a number of the limitations of present approaches to modelling human reasoning and team behaviour. Practical experience in Australia with DSTO and other organisations has shown that multi-agent architectures are suited to implementing simulation and decision support systems.

Several DSTO applications have demonstrated that BDI agents provide the most appropriate underpinning architecture for representing human decision making, including a formalism for expressing team structures and behaviours necessary to model C3.

The success of these applications has stimulated current research into teams, recognition of intentions and learning, and has been accompanied by the recent development of JACK by Agent Oriented Software, a third-generation agent kernel.

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