Intelligent Human Variability in Computer Generated Forces

Agent Oriented Software
A Case Study

1. Introduction

This case study describes the application of agent technology to modelling human variability in military environments. It outlines a system that was commissioned by the UK Ministry of Defence (MoD) and implemented by Agent Oriented Software Ltd. The objective was to offer a simulation environment for studying how people alter their decision making and interactions with other military personnel when influenced by various moderating factors, such as heat, tiredness, consumption of stimulants like caffeine, as well as battlefield experience and cultural factors. Using agents to model human behavioural change in the military context was a novel approach, and the final system achieved a higher level of realism than previous synthetic environments in military training.

2. Human cognition modelling as application domain

Simulation and modelling are extensively used in a wide range of military applications, from development, testing and acquisition of new systems and technologies to operation analysis and provision of training and mission rehearsal for combat situations. In particular, distributed simulation environments for use in training and analysis drive much of this work. For example, simulation exercises involve a few dozen real people with the remaining hundreds or even thousands of other battlefield entities being computer simulations. As the human element is a key success factor in combat situations, the value of computer models of combat are greatly affected by their ability to accurately represent the range and variability of expected human behaviour.

3. Limitations of existing CGF systems

In the last decade, significant advances have been made by the Computer Generated Forces (CGF) and Semi-Automated Forces (SAF) communities to make synthetic military environments more realistic. These have been mostly in terms of 3D graphical interfaces for training, and high-fidelity sophisticated modelling of physical aspects of vehicle movement and damage caused by weaponry in different geographical environments.

However, human reaction, adaptability and decision making in these environments are still little understood, and their modelling is still fairly simplistic. In particular, conventional software approaches make it difficult to model with sufficient fidelity the effect of moderating influences on human behaviour (e.g. external, environmental conditions like heat, humidity or cold, or internal conditions like caffeine intake, jet lag, etc.). Current CGF systems (e.g. Brawler [2], CAEN [3] and the SAF product family [3]) do not adequately model such complex human behaviour because they derive knowledge from prescribed tactics, showing what people are meant to use in the field, and not what they actually use. These systems lack significant situation awareness capabilities, realistic sensitivity to moderating influences, or realistic mechanisms for learning from experience (adaptability). They use pre-scripted behaviours for controlling the entities within the simulation so they are designed to behave predictably, usually according to doctrine, which makes them unable to respond to unexpected events.

Current CGF systems also lack the ability to generate useful self-explanation (hence it is hard to trace system behaviour to see if it accurately illustrates human behaviour). More realistic information therefore needs to be incorporated into these systems to reflect more complex situations and human behaviour. Yet, due to this largely rule-based approach, these systems are difficult to change and integrate, as they require expert knowledge in a specialised area.

As a result, these limitations continue to restrict the wider use of CGF systems as a means of complementing conventional operational analysis and training techniques used by the armed forces of the UK, such as increasingly expensive military exercises.

4. The Human Variability in Computer Generated Forces project

A more suitable approach to modelling the cognition of military personnel is the agent metaphor. Agents are good for both interacting with humans and modelling human behaviour due to their rational and autonomous properties, as well as offering reliability in complex, distributed and real-time systems. While there has been some research, and in addition some implemented systems, that use agents to model military personnel performance in terms of situation awareness, choice of tactics, etc., little investigation has been undertaken to understand how cognitive processes change as a result of moderating influences. The Human Variability in Computer Generated Forces (HV-CGF) project focused precisely on this aspect, aiming to develop a framework for simulating behavioural changes of individuals and groups of British military personnel, when subjected to moderating influences.

4.1 Agent Oriented Software

The Agent Oriented Software (AOS) Group is a software company specialising in the development of intelligent systems, particularly for real-time distributed control. Founded in 1997 in Melbourne, Australia, AOS has successfully built up a multi-million dollar annual revenue stream through partnerships with a variety of defence-related organisations, using agents to simulate humans and human behaviour in a range of adverse conditions. Although its most successful applications have been in Aerospace and Defence, AOS has a broader portfolio of projects covering industries like manufacturing, telecommunications, retailing, government, finance, application areas including distributed systems, scheduling, real-time systems (e.g. air traffic management and robotic manufacturing), call centre customer management, order management and provisioning, and business process management.

4.2 JACK Intelligent Agents™

Unlike other agent-based systems, the HV-CGF application was not built as a standalone system using a particular agent oriented methodology or framework, but rather as a set of components in order to facilitate integration with companies' legacy systems. The project built on the JACK Intelligent AgentsTM toolkit developed by AOS, a commercial Java-based environment for developing and running multi-agent applications.

JACK was particularly appropriate for several reasons. It incorporates the Belief-Desire-Intention (BDI) reasoning model, proven to effectively model certain types of behaviour, like the application of standard operational procedures by trained staff. JACK also includes facilities for the creation of intelligent team behaviour through the advanced JACK Teams model, while the JACK Agent Language extends Java with constructs for agent characteristics, such as plans and events.

However, despite these advantages, JACKTM and its applications had not previously addressed the problem of modelling moderating influences such as emotion and fatigue.

4.3 Solution framework

The main objectives in HV-CGF were first to extend the BDI paradigm by developing a cognitive architecture that includes psychologically-based constraints and the influences of moderators, and second to develop a software system for validating this architecture and that could be integrated with CGF systems. To achieve these objectives, the HV-CGF team developed a multi-layer solution framework, the architecture of which is depicted in Figure 1.

At its core the framework has the JACK Cognitive Architecture (Co-JACK), a cognitive modelling layer on top of JACK, for enhancing agent functionality with psychological attributes. Using these attributes, cognitively-plausible agents can be developed to simulate human psychological parameters, such as the capacity of human memory to handle multiple concurrent tasks, the perception and speed of reaction to events from the battle-space, and the ability to choose from different problem solving tactics. This layer can be used to develop various cognitive models.

The influence of internal and external moderators is then modelled as an independent layer, through a set of Behaviour Moderators, one for each influencing factor that modifies the agent's psychological attributes. These were implemented as Behaviour Moderator Overlays that can be plugged into the JACK Cognitive Architecture.

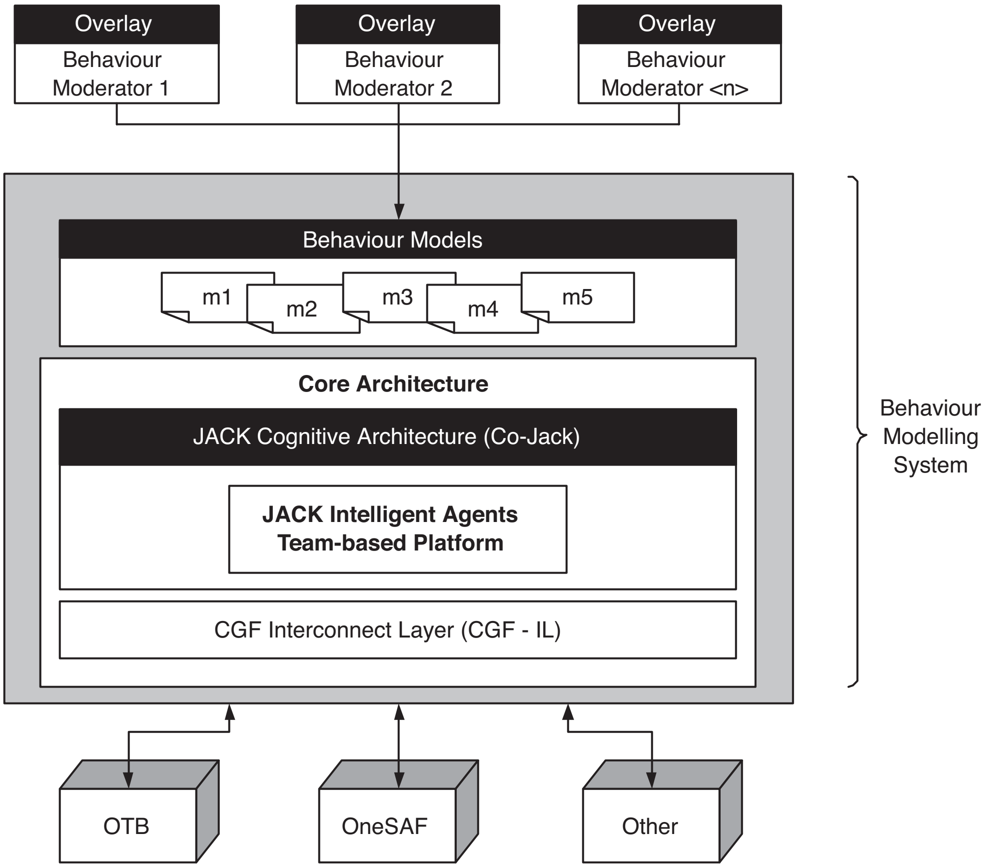

Figure 1: Layers of the HV-CGF System Model [Source: http://www.agent-software.com/shared/solutions/hvcgf.html]

Also part of the core architecture is the JACK Intelligent Agents Team-based Platform, which was implemented using JACK's team based agent capability, to model human variability at team level. It facilitates the design, configuration and execution of a collection of agents organised in military structures realistic to the UK army. Each team member is a rational agent able to execute actions such as doctrinal and non-doctrinal behaviour tactics, which are encoded as JACK agent graphical plans.

The integration of Co-JACK with different current CGF systems (e.g. OneSAF Test Bed (OTB)) is achieved via a CGF Interconnection Layer (CGF-IL), which is used to visualise project outputs using CGF entities (as each CGF entity is controlled by a JACK agent).

The multi-layer model has the advantage of allowing the independent development of each layer, with well-defined interfaces between layers, thus ensuring high cohesion and low coupling between the layer of Behaviour Moderators and the agents and CGF layers. In this model, each entity in a battle scenario (e.g. tank, soldier, tank commander, etc) is a JACK agent, and agents are grouped in teams with associated team roles (e.g. commander, observer, etc.). Entities respond to events (e.g. attack the enemy) by selecting a particular tactic that depends on its role, on the state of its beliefs and on the rules of the mission. Modelling the moderating influences is done by changing the belief state. For example, an agent is ready to change its beliefs based on the tiredness of a soldier. The result of such a change is that the currently executing plan terminates and another plan's execution is started.

In addition to adding cognitive properties to agents, the JACK team infrastructure was also extended to allow redistribution of team roles at runtime. Other changes to the BDI model were also necessary due to human cognitive limitations in comparison with the execution performance of the agent system, in order to improve the realism of agent behaviour. For example, there are limitations in human cognition in terms of the number of options considered in decision-making, there are time delays and limits to the number of issues or beliefs that can be dealt with at the same time. By contrast, BDI agents can deal with a virtually unlimited number of plans concurrently, hold a virtually unlimited number of beliefs, etc. The model was not modified by limiting the number of plans or beliefs of the agent but by associating a larger time delay when deciding on the tactic used, when choosing between options, etc. It was validated through feedback from cognitive science and military experts and by running the model with data (e.g. plans) that had been used in experiments with other cognitive architectures (e.g. Soar) and then comparing the results.

5. Demonstration scenario

The system was demonstrated through a scenario chosen by the MoD Directorate of Analysis, Experimentation and Simulation to have both high military relevance and operational feasibility. This scenario was a mission with six attack helicopters attacking a ground target.

The objectives of the demonstration were to illustrate the concept of cognition and behaviour moderation in the Co-JACK environment both at individual and team levels. In particular, the demonstration showed how caffeine and sleep deprivation affect perception, situation awareness and decision-making, and how the selection of doctrinal and non-doctrinal behaviour is affected as a result. For example, when a soldier is tired, creating situation awareness may take longer than otherwise, and perception of the route for attack may be different. This was tested by showing how changes in psychological variables within Co-JACK determine changes in the behaviour of the entities in the OneSAF system, thus demonstating the integration of Co-JACK with the CGF system.

However, the demonstration also revealed two areas where the system required improvement, and which were therefore taken into a subsequent project phase for further development. The first was modelling the variability across agents of perception of the world as a result of moderation of behaviour. The second area concerned ease of use by non-experts, especially because demonstrating value to stakeholders was important. There was a fair amount of difficulty in using the system both in terms of writing accurate tactics for the model, and tracing and understanding overall system behaviour due to the complexity of inferences at the agent level and of the interactions between agents. Thus, dealing with the combinatorial explosion of different outcomes in the battle-space, and how this explosion can most usefully be presented for decision support or training were two of the objectives for further development.

6. Challenges

The project raised several challenges, both technical and managerial. The technical challenges were mostly related to integration aspects:

- The integration between the agent-based system and the CGF systems raised several problems. For example, there was a need to use different time models in the agent model and the CGF system in order to synchronise between the processes run by different entities. Other integration problems often resulted in having to re-program parts of the software (e.g., in the CGF case).

- Matching cognitive science concepts to computing concepts and then linking back and interpreting simulation results according to cognitive principles was also problematic, not least because using agents was a novel modelling approach for the project team. Validation was therefore an important step and was achieved by comparing the results of the agent-based simulation with those produced by other cognitive architectures that had previously been validated through experiments with real humans.
- Because much of the moderation of behaviour is time-based (e.g., influence of caffeine reduces over time), the integration of time-dependent variations in beliefs across all agents was difficult to model, due to the large number of variables involved and the associated statistical uncertainty.

In general, the integration across three different technologies (agent, cognition modelling and CGF) was one of the main risks of the project, and the use of a clear and regularly-updated plan for mitigating the risks was important throughout the whole project lifespan.

A series of non-technical challenges were also encountered:

- The knowledge acquisition and engineering processes were difficult. Gathering information about the military environments in a form coherent with the underlying model, from military experts with little understanding of, or interest in, agent technology, and with limited time available for discussions, proved challenging. Subsequently, converting this acquired complex knowledge into rules added an extra difficulty.
- Equally important was the managerial overhead in having to coordinate development and integration from several subcontractors at different sites.

7. Business model and project management framework

The project started in February 2003 as a partnership between Agent Oriented Software Limited (Cambridge, UK and Melbourne, Australia), QinetiQ (Farnborough and Malvern, UK), Pennsylvania State University (Pennsylvania, USA), and the University of Melbourne (Australia). It was commissioned by the U.K. Ministry of Defence (MoD) under the sponsorship of the Directorate of Analysis, Experimentation and Simulation (DAES).

7.1 Contract

The contract was won after a hotly contested invitation to tender, with a proposal that was supported both by a strong technical argument and a good business case. The technical competency of the proposal was evaluated by the Defence Science and Technology Organisation (DSTO), the commercial value was judged by a commercial arm of the MoD, and final approval was given by the Director of the DAES.

On the technical side, AOS's expertise in agent technology and a good record of agent-based implementations for defence applications, combined with a strong relationship with DSTO were also positive factors in winning the contract. A strategic agreement established in 2001 between AOS and DSTO, which covered the use by DSTO of JACK Intelligent AgentsTM, thus bringing to AOS the benefit of collaborative evaluation and integration of intelligent agents into simulation systems used by DSTO, also contributed to this. However, the business value of the project was equally important, and the technical proposal had to be accompanied by a business case. This contained, for example, an outline of high-level objectives and the time plan of work breakdown for each of the two years, a list of necessary resources, (both in terms of staff and other financial resources such as the number of JACK licenses necessary for contributing partners), as well as a statement of stakeholder relevance.

7.2. Team

The team included a Project Director, who also acted as the main customer liaison, a Project Leader responsible for the day to day management of the project, a Technical Architect, several Java developers and a Technical Author. Expert knowledge of human cognition and human behaviour modelling was provided by Professor Frank Ritter (Pennsylvania State University) and Emma Norling (Manchester Metropolitan University), while Qinetiq as subcontractor was responsible for integration with the CGF system, and for the acquisition, modelling and encoding of expert knowledge, and building of scenarios. As there had been few prior experiments and results on human behaviour in harsh environments (hot, dirty, wet), a team of subject matter experts was used to ensure realism. A Military and Technical Advisory Panel of experts from the DSTL and the UK Army was established, bringing both expertise on the military domain (e.g. doctrine and tactics used in the army) and hands-on experience in combat situations.

7.3 Commercial model

The commercial model was largely determined by the framework of research, development and acquisition of the MoD. As part of a strategy of de-risking early technologies, the MoD has set up a framework of monitoring and assessment of technology, whereby leading-edge technology that is inherently risky is assessed against several levels of readiness. These levels cover phases such as concept formulation, proof-of-concept, validation in different environments, through to final deployment, usually spanning between 8 and 12 years in total. The objective is to ensure that technology reaches the level of readiness where it can be made available to the MoD's equipment supplier base to incorporate it into defence products. According to this framework, the HV-CGF project was in early readiness stages (but at higher levels than previous AOS projects). Thus, the customer of the two-year project phase described in this case study was DSTO, who monitored the project and ensured that technical requirements were met and who bought the product. However, in order to increase the technology readiness level towards deployment in military applications, a second two-year phase was commissioned by the MoD and has recently begun. One of the aspects to be addressed when making the system more ready for acquisition is to improve its user-friendliness. Thus, one of the objectives of this phase is to develop a graphical interface to illustrate the system's utility for training and simulation.

8. Lessons and experiences

Mutual benefit was gained by the agent and defence communities, in that a new application area for agents was demonstrated, as well as showing agents to be an innovative but feasible solution to the problem of modelling moderated behaviour in distributed simulations. This achievement raised further interest in agent technology within the defence community, particularly in applying agents to other types of simulations to solve problems previously deemed difficult or unsolvable, thus pushing agent technology towards exploration and development of new areas.

9. Summary

This case study has presented a novel application of agent-based technology to modelling changes in human behaviour due to moderating influences. In particular, the agent system modelled how the situation awareness and behaviour of military personnel are altered over time in response to moderating factors such as environment, caffeine intake, etc., and how this can be integrated and visualised in a Computer Generated Forces system. The application demonstrates how the fidelity of a CGF system can be improved by modelling, with increased accuracy, realism and dynamism, the behaviour of military entities and their interactions, and changes with time, thereby increasing confidence in the credibility of CGFs.

References

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