Towards Complex Team Behaviour in Multi-Agent Systems

Dr Andrew Lucas, Dr Ralph Rönnquist, Nick Howden, Andrew Hodgson
Agent Oriented Software Pty. Ltd.
PO Box 639
Carlton South, VIC 3053
Australia
<firstname.surname>@agent-software.com

Russell Connell, Geoffrey White, Dr Jonathan Vaughan
Defence Science and Technology Organisation, Land Operations Division
PO Box 1500
Salisbury, SA 5108
Australia
<firstname.surname>@dsto.defence.gov.au

Abstract. Team Based Agent Technology (TeBAT) is a programming framework supporting specification of coordinated activity among software agents. It was developed for simulations of land operations in defence, and incorporates both automated path finding in complex environments and distributed control of team movement and operations. As a generic framework, it is applicable to a larger range of domains, including the coordinated operations of autonomous vehicles.

From the initial evaluation of existing team approaches, one of the outstanding lessons was that team behaviour cannot be ‘bolted on’ to an agent or multi-agent architecture. Rather, teamwork, and support for teamwork, must be built in from the beginning. The approach taken in TeBAT is based upon the BDI (Belief, Desire, Intention) paradigm, which evolved from early work by Bratman[3] on rational agency. Key to this approach is an emphasis on ‘intentionality’, with teams of agents possessing collaborative intentions.

In TeBAT, team movement is characterised as structured flocking behaviours with formation control. Conceptually, each team entity is aware of its place in the formation, and it is aware of any entities around it as well as the terrain and environment in which it operates. The team path finding implements the A* and Dijkstra's search algorithms with modifications: node weightings include team dependent modifiers such as team structure, goals of the team and team knowledge that allow weighting factors to become dynamic. TeBAT further enables dynamic formation and reformation of teams, reasoning over team goal failures at the team level, as well as automatic sharing and aggregation of beliefs between teams and sub-teams.

Applied to land combat simulations, TeBAT has provided a simplifying infrastructure on top of JACK Intelligent Agents™[4]. TeBAT allows team based tactical operations of military doctrine to be captured in an effective way and be played out in simulation scenarios with minimal effort. It avoids the previous laborious construction of complex scripts of detailed entity control, and instead provides a simulation building environment that incorporates team tactics as plug-and-play models.

This paper presents the key concepts of the TeBAT modelling framework, and illustrates its application to cases of coordinated activity. We show that although JACK Intelligent Agents™ provides a full-featured agent development platform, the extension provided by the TeBAT framework brings a significant reduction to the complexity of making agents act as a team. The TeBAT approach to team behaviour is flexible, robust and scalable.

1. INTRODUCTION

The Team Based Agent Technology (TeBAT), which is presented in this paper, is a team modelling framework that was developed for use in computer simulations of military tactics and equipment, in particular those of the Australian Army. As the army environment is quintessentially a team one, a framework for modelling such an environment must incorporate features of teaming. A conclusion from the initial evaluation of existing team approaches was that teamwork and support for teamwork must be built into the modelling framework from the beginning; it cannot be ‘bolted on’ to an agent or multi-agent architecture. TeBAT is a team modelling framework based upon the BDI (Belief, Desire, Intention) reasoning model and implemented as a model extension on JACK Intelligent Agents™. A key to the BDI approach is the emphasis on ‘intentionality’; that a reasoning entity adopts its plans of action with the intentions to satisfy its goals.

The TeBAT framework introduces the notion of teams as separate reasoning entities. The behaviour of a team, and in particular the coordinated activity of the team members, is defined directly for the team entity. Thus, in the software model, each team exists as an entity with beliefs, desires and intentions separate from its members,
and a team plan is distinctly a plan that the team entity performs.

Team plans include steps of computation that are carried out by the team entity itself as well as steps of activity that instruct sub teams to achieve certain goals. A team plan may instruct sub teams to achieve goals in parallel or in sequence, and the framework takes care of ensuring that the planned coordination occurs. E.g., if goals X and Y are to be achieved in sequence, then goal Y is instructed after that goal X has been achieved, and correspondingly for parallel goals.

A role definition includes both an enumeration of the goals that a team performing this role needs to be able to achieve, and an enumeration of the counter-goals that a team performing this role can request to be achieved by the composite team. Similarly, a team definition includes both an enumeration of the roles it requires sub teams for, and of the roles the team itself is able to perform. These definitions, for both teams and roles, are type definitions, which thus define team and role types. Any particular team structure is obtained by instantiating individual teams (of defined team types) and attaching them as role fillers for each other.

TeBAT was developed to be used for simulations of land operations in defence. To model this environment it provides means to capture several aspects of team operations, including:

- a hierarchical command structure
- team oriented activities
- team intentions
- extensive reasoning over plan failure
- team reformation and re-organisation
- connection of beliefs between teams up and down the command hierarchy
- autonomy at each command hierarchy level

The modelling framework further includes support for automated path finding in complex environments. Special attention was paid to these aspects, since basically all land operations simulations involve utilising terrain knowledge within the planning and tactical reasoning. This kind of reasoning support is also applicable to a larger range of domains, including the coordinated operations of autonomous vehicles.

2. MODELLING TEAM STRUCTURE

The notion of ‘team structure’ is used in reference to the way teams are composed of sub teams or individuals taking on certain roles. As mentioned, teams are modelled as distinct entities, and they are related by means of performing certain roles and requiring sub teams that perform certain sub roles. Roles are themselves modelled and defined in terms of the constraints and requirements they imply of the teams that can perform these roles or require of sub teams in these roles.

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Figure 1 illustrates a team structure definition. It is an example of a simulation scenario that includes a team of MotorizedPlatoon type, which is composed of GunMen, Drivers, and PlatoonCommand roles, and which can perform ScoutPlatoon, SupportPlatoon, and TransportPlatoon roles. The actual simulation scenario will include an actual team structure that is formed by instantiating and naming individual teams, and then attaching them as role fillers for each other. This is the team formation process, which eventually organises the teams into a team structure.

In general, teams may come about and cease to be dynamically throughout a simulation scenario, and they may also change role filling relationships dynamically. Such team re-formation may, for instance, occur due to a change in the task to be performed, or to reflect ‘casualties’ in the simulation scenario.

The TeBAT team definition further includes a means for declaring belief connections along the team structure. Through such connections, beliefs of a team are maintained by automatic propagation and updated automatically when beliefs of a team member change. For instance, in a military environment, reports flow through
the chain of command in a semi-automated manner. It is natural to model this by a team structure that corresponds to the command structure, and then the reporting chains can be modelled as connections between team and sub team beliefs. E.g., a platoon team’s belief about its ‘location’ is perhaps a computation based upon location beliefs of its members.

For example, a simulation scenario may include an InfantryPlatoon team that requires three Section roles. The actual team structure may then consist of an InfantryPlatoon team with three distinct role-fillers, each performing in a Section role (see figure 2). By filling the Section role, the role-fillers are obliged to perform in that role, but each of the Sections may have additional skills that may be useful within a specific task. When the InfantryPlatoon is establishing the task team for a task, it may ‘look at’ the three role-fillers in more detail to ascertain their appropriateness for the positions of the task, rather than placing them at random. For instance, a frontal assault task as illustrated in figure 2 requires one Section for the assault and one in support. Which particular sub team to use for each position of the task is decided based on their skills and current morale – perhaps with the assault team being the Section with the highest morale.

3. MODELLING TEAM TACTICS
The initial aim for TeBAT was to support the modelling of tactics in computer simulations of military operations. These tactics are typically team tactics that involve coordination of sub team activity, and in general, TeBAT was developed to support the modelling of coordinated activity.

1.1 Team Tasks and Task Teams
A team structure captures the ‘obligation’ relationships between teams that in a direct way corresponds to the military command-and-control structure. At the same time, in most cases teams are able to take on multiple simultaneous missions, which are carried out by different, maybe overlapping, groups of sub teams. TeBAT includes the concept of task teams as being transient sub-groupings within teams, dynamically formed for the purpose of performing particular team tasks. The task team concept offers a powerful addition to the more long-term team and role structures as it facilitates the specification of dynamic team structure formation on the basis of the requirements of particular tasks. The task team concept provides a means of selecting actors for a task based on skills or current states of candidate sub teams rather than merely relying on the role and team types.

It is an initial step of a team plan to establish the task team for carrying out the plan. This is done by selecting which role fillers within the team structure to involve in the various positions that are needed for the task. The establish task team step of a team plan may involve any amount of reasoning by the team entity, as well as negotiations with the candidate sub teams.

The army uses many tactical formations when moving. These formations change based on the physical environment and the tactical environment. Formation movement is also an example of team tactics that should be simple to express in a team modelling framework. TeBAT’s support for movement in concert could equally be applied to control of autonomous vehicles. It could be used to manage coordination of several vehicles, or for synchronising multiple actuators within a single vehicle – for example, where different configurations are required for different environments.

Flocking algorithms [1] have been developed to model coordinated animal motion such as the flight of bird flocks and movements of fish schools. The flocking algorithms generally allow control of certain aspects, such as flock direction, the maximal distance between flock members and the overall flock speed, to construct a
model. However, flock models tend to display semi chaotic behaviour within the bounds of the flock itself. Military formations have a certain degree of rigidity in the positioning of the individual soldiers within the formation that is quite different from the loose chaotic flow that flocking algorithms provide.

Within the team modelling framework, formation rigidity is ensured by making each entity aware of its place in the formation relative to other entities. The entity is then responsible for keeping it’s position within the formation as well as the maintaining an overall direction and speed. The entity moves in a formation by means of changing its direction and speed in accordance with a set of fuzzy rules. These rules take into account the required speed and direction as well as the distance and bearing to the entities that this entity is maintaining station on. The super team provides the information on required heading and speed as well as the formation to the sub-teams. Each sub-team then maintains its position in the formation by using the fuzzy rules.

1.3 Path Finding Through Complex Environments

TeBAT provides a means for finding paths through a complex terrain, taking into account multiple environmental factors. This facility is currently used in the specification of behaviour of ground forces in military simulation, but could also be applied to the control of autonomous vehicles.

Path finding within TeBAT utilises a generic form of the A* algorithm [2], combined with the concept of area type and domain heuristics. Area Types are shapes in two or three dimensions of areas (volumes) that the team has knowledge of. This includes roads and buildings as well as non-physical entities such as enemy line of sight footprints or just ‘desirable places’ according to current doctrine. Multiple Area Types can coexist in the one location, essentially providing multiple overlays to the map, and the position of an Area Type can be changed while an optimal path is being searched.

Teams can have different heuristics for associating weights to Area Types. For instance, a simple road following heuristic might associate low weights only for ‘nodes on a road’, while a more advanced road following heuristic may instead associate low weights for ‘nodes next to a road’. The more advanced heuristic would prefer the team to follow the edge of the road rather than walk down the middle of it. Heuristics are stackable, allowing, for example, a heuristic that prefers following roads together with a heuristic that avoids enemy line of sight footprints.

The Path Finder Utility has been developed to provide navigation for Agents and Teams inside the Close Action Environment Simulation (CAEN) Advanced Urban Environment (AUE). The concept of ‘Area Types’ allows for easy adaptation to any system requiring automated navigation. The dynamic nature of the utility allows for events to occur (e.g., detection of enemy presence), which change the outcome of the path generated. As the Area Types are generated both statically and dynamically the Path Finder is similar to robotics navigation today, with optimisations for performance in a computer simulation environment.

4. SUMMARY

TeBAT is a team modelling framework developed to support modelling of tactics in the simulation of military operations. It is however a generic team modelling framework that can be applied to a range of domains involving structured and coordinated activity. TeBAT is based on the BDI reasoning model, which is a successful approach to programming of autonomous agents, and it is built as an extension to JACK Intelligent Agents™.

TeBAT provides support for modelling team structures and coordinated activity within these structures, and it supports in particular the description of team activity in the context of dynamic team structures. Task Teams add the ability to make a skills or status-based choice of transient sub-groupings within a team for the purposes of a specific task.

TeBAT supports complex connections of team belief structures, both up and down the team hierarchy.

In order to support navigation through complex terrain, TeBAT includes algorithms for path finding. These take into account multiple Area Type overlays, including such things as terrain features, buildings and even enemy line-of-sight footprints. The heuristics used to associate weights with Area Types are defined separately and may be stacked together. TeBAT also includes means of moving team structures in formation. These features of TeBAT would be useful in the coordinated control of autonomous vehicles.

REFERENCES