Modelling Peace Support Operations: An Agent-Based Approach

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ABSTRACT AND INTRODUCTION

There is an extensive array of models available for traditional combat operations but the modelling of peace support operations is a relatively new area. With the emphasis of many armed forces switching to operations other than war, it is clear that more research in this area is needed. Here we present our ideas for an agent-based model to represent a town recovering from conflict, and confirm previous findings regarding the need to modify and extend the approach used in agent-based combat models, such as MANA, when representing peacekeeping scenarios.

This paper describes the research we are currently undertaking into modelling peace support operations. We are particularly interested in the application of complexity theory, and specifically self-organised criticality. Previous work, by Moffat [6], has studied the emergent properties of agent-based combat models and found that ideas from complexity theory can be used to explain the observed results. In order to investigate if this approach can be applied in peacekeeping scenarios we will be using an agent-based model and studying the resultant emergent behaviour.

We begin by examining the theory behind agent-based models, giving a simple example, before looking at two agent-based models of combat, ISAAC and MANA. We then move on to examine two examples of current methods for modelling peacekeeping operations, the DIAMOND and PAX models. Repeating experiments carried out by the developers of the PAX model, we try to model a simple peace support scenario using MANA. Finally we describe some of the basic ideas we will be using for our own agent-based model that is currently in development.

AGENT-BASED MODELS

We have decided that the best way to model peacekeeping scenarios will be to use an agent-based model, and in particular a cellular automata model. In part this is because one of the aims of our research is to find evidence of self organised criticality, many of the models that exhibit this behaviour are agent-based. Self-organised criticality is related to the wider topic of complexity. The theory was introduced by Bak, Tang and Wiesenfeld in their 1987 paper [2] as an explanation for the behaviour of a sandpile model they had developed. A general introduction to the subject is given in the key text [1] written by Bak, a more in depth analysis is given in Jensen's book [4].

In an agent-based model all the entities are controlled by a set of behavioural rules that are implemented at each step rather than by a set of predetermined events. As an example, rather than having an exact route mapped out, agents move according to the situation around them. They may have a goal but there is no guarantee the agent will ever reach it. Before looking at examples of agent-based models of combat we introduce an example of a simple cellular automata model to illustrate the concepts. This will be Conway's Game of Life, described in Wolfram's book [9], a widely studied model with many interesting behaviours resulting from three very simple rules. The model is defined on a two-dimensional square lattice where each cell is defined to be either alive or dead. The cells evolve according to the number of neighbouring alive and dead squares. For the purposes of this model the neighbouring cells are defined to be the eight surrounding squares. The following rules are followed:

1. If a live cell has less than two alive neighbours it becomes a dead cell at the next step.

2. If a live cell has four or more alive neighbours it will become a dead cell at the next step.

3. If a dead cell has exactly three alive neighbours it will become a live cell at the next step.

If none of these situations are applicable the cell remains unchanged. An example model evolution over four time steps is shown in Figure 1. Live cells are shown as black, dead cells are white.

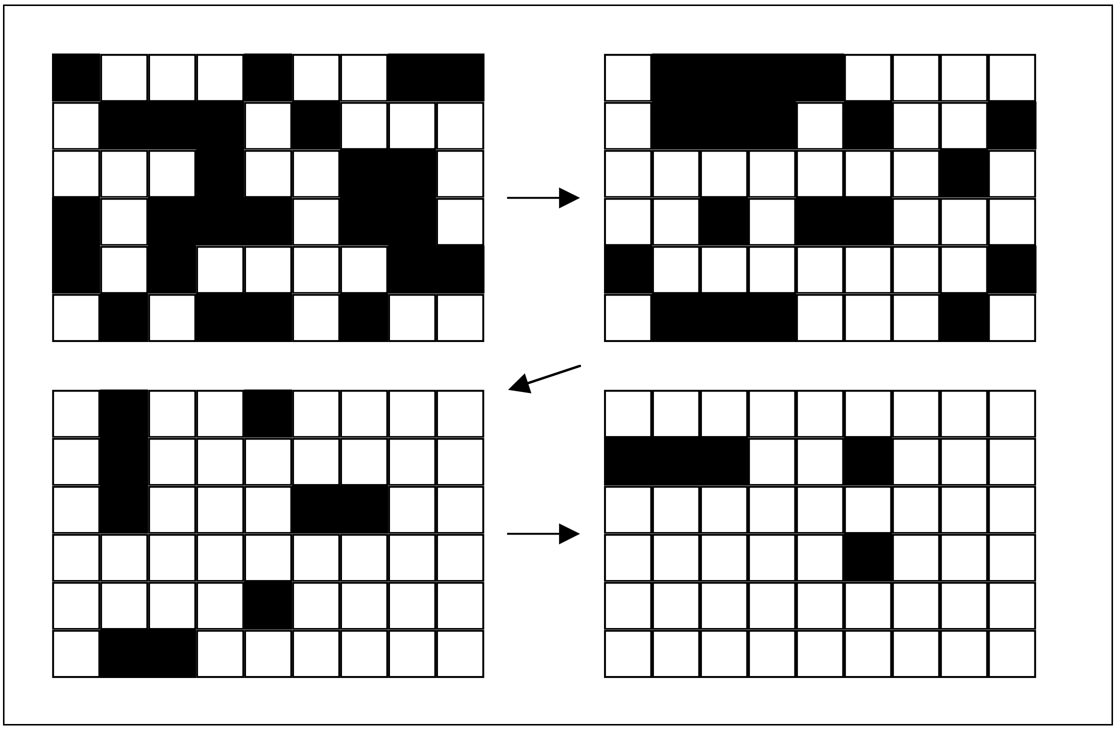

Figure 1: An Example Game of Life.

The Game of Life is used to symbolise simple population dynamics. Rule one represents populations dying out due to isolation or lack of food. Rule two represents overcrowding and therefore too much competition for food. Rule three gives ideal conditions for population growth. In our example in Figure 1 we can see an overall decline in the population.

When studying agent-based models we are looking for emergent behaviour. Examples of emergent behaviour for the Game of Life are stable patterns, blinkers and gliders. Stable patterns, as the name suggests, are configurations that do not change as the model evolves. An example would be a two-by-two square.

A blinker is a pattern that repeats after a number of time steps, an example of a blinker of period two is shown in Figure 2.

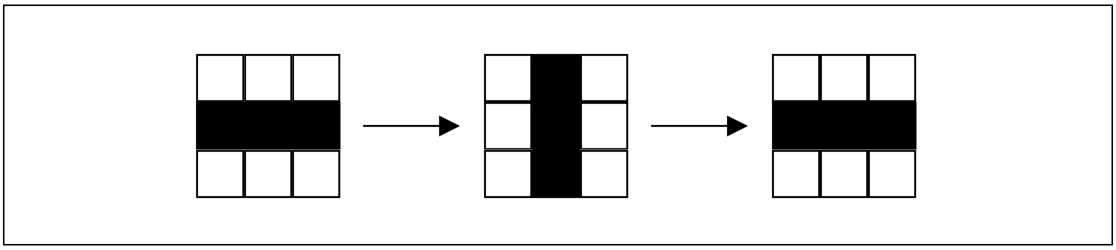

Figure 2: An Example Blinker.

Gliders are a special type of blinker. As well as having a cyclic pattern, the shape is also displaced diagonally by one square so it moves across the grid. An example glider of period four is shown in Figure 3.

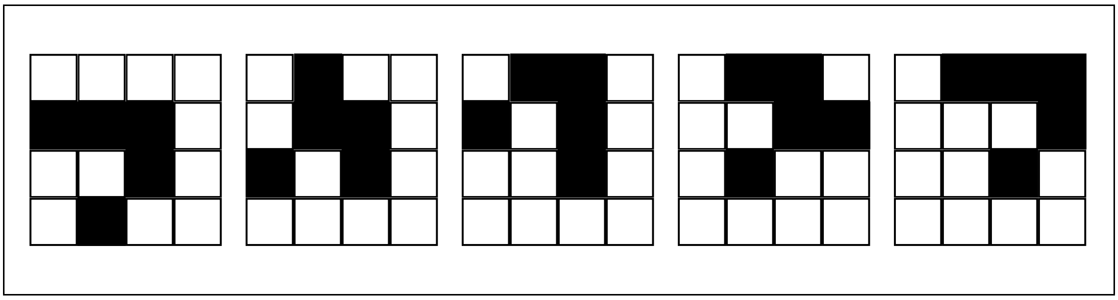

Figure 3: An Example Glider.

AGENT-BASED COMBAT MODELS

We now move on to the far more complex agent-based models of combat. In our research we have been looking at the two models MANA and ISAAC. The acronym ISAAC stands for Irreducible Semi-Autonomous Adaptive Combat. This model was developed by Andrew Ilachinski for the Centre for Naval Analyses in the USA. MANA stands for Map Aware Non-uniform Automata and was developed by Michael Lauren and Roger Stephen for the New Zealand Defence Technology agency. In order to understand the two models we used the user guides [3] and [5].

Each model has five sets of parameters: general battle settings, personality parameters, ranges and constraints, terrain data and weapon data. The general battle settings give the basic defining factors such as squad numbers, size of the battlefield, starting positions and goal locations. The personality parameters are mainly weights determining how much an agent wants to move towards a particular type of entity, such as enemy agents. They can be either positive, negative or zero where a positive weight indicates a wish to move towards that type of entity and a negative weight indicates the agent wants to move away from it. The six personality weights for the ISAAC model are given in Table 1. The ranges and constraints include the usual combat ranges such as sensor and firing ranges and single shot kill probability. There are also constraints on movement and combat which, for example, limit an agent to firing only when there are enough friendly agents within sensor range.

Weight	Entity
W_1	Alive Friends
W_2	Alive Enemy
W_3	Injured Friends
W_4	Injured Enemy
W_5	Own Flag
W_6	Enemy Flag

Table 1: Personality Weights for the ISAAC model

The evolution of the model is determined by the initial settings, movement algorithm and rules of engagement. In MANA and ISAAC the rules of engagement are such that if an opposition agent is within firing range, and all combat constraints are satisfied, then the agent will fire at its enemy. The movement algorithms are more complex: they work on a principle of penalty calculation. The cells an agent can move to are determined by its movement speed, a penalty value is then calculated for each of these valid moves. The penalty function takes into account the number and type of agents within sensor range and uses the personality weights as multipliers. As an example, the ISAAC penalty equation taken from the user guide [3] is given below in Equation (1). Consider the area within sensor range for a Blue agent situated at position $\underline{x}_0$, assume the proposed move location is $\underline{x}_1$. We denote the sensor range for Blue by S_B. Denote the alive friends by $B_1, B_2, \ldots, B_p$, and the alive enemies by $R_1, R_2, \ldots, R_q$. Similarly, denote the injured Blues by $B_{p+1}, B_{p+2}, \ldots, B_n$, and the injured Reds by $R_{q+1}, R_{q+2}, \ldots, R_m$. The notation $d[\underline{a}, \underline{b}]$ represents the distance between the points $\underline{a}$ and $\underline{b}$. The personality weights were given earlier in Table 1.

$$
\begin{aligned}
Penalty(\underline{x}_1) = {} & \frac{W_1}{pS_B\sqrt{2}} \sum_{i=1}^{p} d[\underline{x}_1, B_i] + \frac{W_2}{qS_B\sqrt{2}} \sum_{i=1}^{q} d[\underline{x}_1, R_i] + \\
& \frac{W_3}{(n-p)S_B\sqrt{2}} \sum_{i=p+1}^{n} d[\underline{x}_1, B_i] + \frac{W_4}{(m-q)S_B\sqrt{2}} \sum_{i=q+1}^{m} d[\underline{x}_1, R_i] + \\
& W_5 \frac{d[\underline{x}_1, B_{flag}]}{d[\underline{x}_0, B_{flag}]} + W_6 \frac{d[\underline{x}_1, R_{flag}]}{d[\underline{x}_0, R_{flag}]}
\end{aligned}
\tag{1}
$$

MODELLING PEACE SUPPORT OPERATIONS

In the course of our research we have looked at two models for representing peace support operations, DIAMOND and PAX. The two models are very different, DIAMOND can be used to represent a whole country whereas PAX looks at a much smaller scale operation.

The acronym DIAMOND stands for DIplomatic And Military Operations in a Non-warfighting Domain. The model was developed for Dstl in the UK for the representation of operations other than war and uses scenarios involving peacekeeping forces, non-military organisations, civilians and local military factions. DIAMOND works on an arc and node network where the nodes represent a town or group of villages and the arcs are the valid routes between them. The personnel in the model are grouped together, for example all the civilians at a node are modelled as one entity. The model is mission-based and stochastic, the entities are given a mission and work towards it until it is completed or it is changed by their superior and relayed through the communications network. Further information on DIAMOND is given in Taylor and Lane's paper [8].

The model PAX was developed in Germany by EADS Dornier GmbH. In their paper [7], Schwarz and Bertsche describe the background to the model's development. They tried modelling a simple food distribution scenario using the agent-based combat model, MANA, and identified various issues that needed addressing in order to model their scenario. As a result a new agent-based model PAX was developed using the social science model PECS as a basis.

We wish to develop a model that fits between DIAMOND and PAX in scale in order to model the events that happen at a node in DIAMOND. There is no real representation of what is happening at this node level in DIAMOND and although there are statistics that give, for example, casualty numbers and cause of death, there is nothing to show the actual events occurring at the node. Typically this node might represent a town or group of villages and hence to represent the variety of peacekeeping operations that might occur we need a model that is greater in scope than PAX.

EXPERIMENTS

Schwarz and Bertsche's paper [7] details experiments they have carried out using MANA in order to test its suitability for modelling a simple food distribution scenario. We decided to repeat their experiments to see if we reached the same conclusions. In fact, after correspondence with the authors it was found that we had simplified their scenario somewhat so our results were not directly comparable.

There are 60 civilian agents split into three equal groups, and one group of 15 military agents. The agents were initially randomly distributed in the areas shown in Figure 4. The civilian agents start spread out over a relatively large area whereas the military agents are grouped together. The military agents move around the grid passing through each civilian group in turn. The civilians move towards the military agents when they arrive and then move away from them, this represented the handover of food. We set the rules of engagement such that the civilians had a low single shot kill probability (SSKP) and the military agents had a higher SSKP but only engaged in combat if fired on.

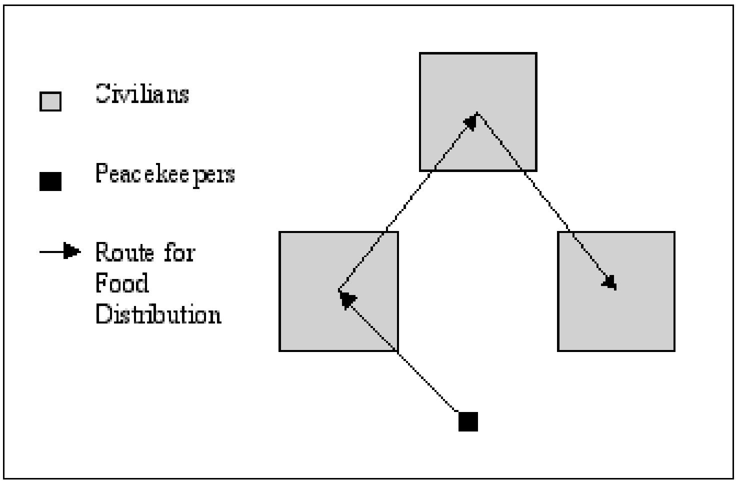

Figure 4: Initial Settings for Distribution Scenario.

After running this scenario we found that we had very high casualty numbers that led to some changes being implemented. Initially we had the military agents pause at the centre of each civilian group, but this led to the majority of the agents being killed so it was decided that the military agents should not stop. This reduced the casualty numbers but they were still very high. Consequently we reduced the SSKP for both sets of agents. This succeeded in reducing the casualty numbers further but was not ideal.

In their paper [7] Schwarz and Bertsche came to the conclusion that MANA was inadequate for modelling civilians. Since the agents have to be modelled as rivals we can either have a scenario with a lot of shooting or none at all. Our experiments confirmed these findings. In addition we can say that we can alter the parameter values in order to obtain more realistic casualty numbers, but this is obviously an unsatisfactory situation. In order to represent peace support operations more realistically we need a model that allows for a greater variety of behaviours.

SUGGESTED IMPROVEMENTS

Even from looking at a simple distribution scenario we can see that MANA will not be suitable for modelling peace support operations. It has therefore been decided that we will develop our own agent-based model for this purpose. We will be using some of the ideas from MANA whilst creating additional parameters in order to represent the added complexity of peacekeeping operations.

We need to introduce civilians into the model and define them differently to military agents. In addition we will also be modelling the support agencies and local militia so we will have four types of agent in comparison to MANA's one. It seems that the rules of engagement in MANA need to be modified for peace support scenarios. In the food distribution scenario, for example, it would be better to give the civilian agents a probability of shooting dependent on the situation rather than them just firing at the military agents once they are within sensor range. We will also be defining psychological factors for the local agents that will influence any conflict that may occur. These will be 'fear', calculated for individual civilian agents, and 'tension,' calculated at each cell containing civilians or local militia. There will also be a factor 'acceptance of occupying force' which will be calculated for each group of local agents in the model, it will incorporate both events occurring in the model and a random factor to represent outside events that would be reported by the media.

CONCLUSIONS AND FUTURE WORK

We have confirmed Schwarz and Bertsche's findings regarding the limitations of MANA when modelling peace support scenarios and, in particular, the difficulty when modelling civilians. We have suggested improvements that could be made, and we shall be incorporating these in the agent-based model we are currently developing. These changes include revised rules of engagement such that agents have a probability of firing related to certain psychological factors.

Our next task is to finish developing our agent-based model for representing peacekeeping operations. We will also need to test the model with a range of scenarios incorporating typical tasks facing peacekeeping forces. In order to detect any complex behaviour it is anticipated that each scenario should contain a range of tasks. When we have a working model we will be examining any emergent behaviour, in particular we will be looking for evidence of self-organised criticality.

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