Simple land battles using agent based modelling

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In this model battle between attackers and defenders takes place on land. The model is realized via agent based modelling in which individual agents make decisions in every time step. This is modelled by different strategy that are explored in the course of the project and leads to surprising and interesting observations.

I. INTRODUCTION

In this model battle between attackers and defenders takes place on land. In order to make our project interesting we have taken example of Infinity war which is a fictitious battle characterized by two warring armies of Avengers and Thanos. Here we use agent based modelling(individual agents make decision in every time step) to examine the battle and explore various effects of initial conditions and strategy on evolution and outcome of battle. Our battle model currently describes conflict between Thanos army which is an Attacking army and Avengers which is a Defensive army.This model is important for study because it can be used to find useful strategies and predict outcomes in real-life battles and related problems involving conflict between two parties[1]. The problem is simulated using the Cellular Automata.The simulations involve deployment strategies which result in occupation of the sites by the combatants. The initial conditions are provided in the form of random allocation of the members of both the army in the battleground along with some land which is unoccupied.

II. MODEL

This model describes a simple battle between Avengers and Thanos army. Former is defending army and latter is the attacking one.We consider competition between well matched sides i.e. we focus on cases where both sides have equal attack and reserve capabilities. We will consider eventual territorial dominance to decide victory of an army.
Let us begin by considering a square lattice of length L where the battle will take place.At the start of the battle each side is allocated equal reserves $A_0 = B_0$ which represents weapons,troops and resources etc. A and B represents avengers and thanos army at any given time. To initialize the battle, we randomly place the avengers force on the battlefield. This is done by taking a fixed number of agents from their initial reserve A_0 and placing them randomly upon the lattice with a given density ρ_A (ratio of sites occupied by the avengers to the total number of sites on the lattice (L^2)). Table I summarizes the symbols we use in our study and their meaning.

Side	Symbol	Definition
A : Avengers	A_0, A	Initial/Final avengers reserve
	ρ_A	Ratio of sites occupied by A
	a	Avengers force level
B : Thanos	B_0, B	Initial/Final Thanos reserves
	ρ_B	Ratio of sites occupied by B
	b	Thanos force level
	R	Search range for deployment
Lattice variables	L	Length of each side of lattice
	$h_{xy}(t)$	sum of a and d at position (x,y) in lattice at t time

TABLE I: Description of notations used

A. Assumptions

The assumptions that are considered in order to model the battle are as follows :

- There are only two type of people in the battlefield A: Avengers army and B : Thanos army.
- The model assumes $'symmetric'$ battle which means that strength/force levels of both the sides are equal ($a = b$)
- Avengers and Thanos will deploy their army according to different algorithm one after the other i.e while one army is drawing from reserves and deploying, the other army waits till former army have deployed.
- The combatants do not move in the battle but capture sites. This is fundamental rule of agent based modelling.[1]
- Initially ,Avengers and Thanos both deploy their army randomly with ρ_A and ρ_B density. ρ_A is constant for all the iterations while ρ_B is dynamic.
- Agents are distributed such that the percentage of sites acquired by newly deployed agents is ρ_A or ρ_B. It is independent of how many sites avengers or thanos already occupies.[2]
- Thanos army can only deploy new agents at any time from the sites they have occupied initially.
- Thanos army always deploys maximum size of their force level. Here, in our model $b_{max} = -2$.

B. Initial condition

- Lattice size (L) - Battle between Avengers and Thanos is modelled using cellular automata on a square lattice whose edges have length L. Throughout our project battle will take place on a 50x50 lattice i.e. $L = 50$ because for smaller sizes of lattice the intelligent strategy of attackers is of no use and for large sizes we observed that computation increases to a great extent and results fairly remained the same.

- Strength/force level (a, b) - As the battle is symmetric and hence force level/strength of both avengers and thanos army are same. Strength values for avengers is given by $a = +1, +2, ... + a_{max}$ and values for Thanos army is given by $b = -1, -2, ... - b_{max}$. For the sake of simplicity we have considered $a = +1, +2$ and $b = -1, -2$ for our experiment.

- Reserves (A_0, B_0) - Initial reserves A_0 and B_0 are also taken to be same. It's value is set to be $50,000$ throughout our battle model i.e. $A_0 = B_0 = 50,000$. Because, for small values results are inconsistent and for large values their is more computation without much change in results.

- Density (ρ_A, ρ_B) - Now, at initial time $t = 0$,the avengers(A) are randomly distributed on the lattice with initialized defence density ρ_A and Thanos(B) army also deploys randomly from their reserve with initialized attack density ρ_B.

C. Deployment Rules

After the initial deployment of avengers and thanos army according to density ρ_A and ρ_B respectively , now the deployment algorithms will be different.We have used random strategy for the defenders i.e. avengers . For attackers i.e. Thanos army we have used two types of strategies - intelligent and (a) : aggressive strategy (b) : defensive strategy.
This is inspired from conflicts in Iraq between an insurgent army having access to entire battlefield and less knowledge of terrain (hence random attacks) and an intelligent army whose decision making depends on distribution in battlefield.[1]
These are set of rules according to which both defensive and attacking army will operate:
Avengers : The Avengers will use randomized deployment from their reserve in the lattice with probability ρ_A throughout the whole battle.
Thanos*(Aggressive approach)* : Thanos army takes aggressive approach which means they always deploy resources in direction with greatest density of avengers.
The search for highest density of avengers is done for each Thanos army occupied cell. The size of neighbour cells to be considered for search is given by range variable (R). Hence, considering all 4 direction the thanos army cell receives information of its surrounding (2R+1)x(2R+1) lattice. Now, the resources in each quadrant surrounding the thanos cell is summed up.
The cell under consideration is given by h_{xy}.The rules to decide the direction in which attackers should deploy are:

1. If the computed sum is largest in exactly one of the quadrants then the deployment will take place in that direction. Eg: If the computed sum withing R range is highest in 1st quadrant then :
$$h_{x-1,y+1} \rightarrow h_{x-1,y+1} + b$$
2. If the computed sum of exactly two adjacent quadrants have equal values then deployment will be in adjacent direction. Eg: If computed sum was same in 1st and 4th quadrant then we will do :
$$h_{x,y+1} \rightarrow h_{x,y+1} + b$$
3. If the computed sum in opposite quadrant or any 3 quadrant is same then no new deployment will take place. Although this case has very less probability to occur.

Here, in all the cases b is the maximum force level.
Thanos*(Defensive approach)* : Defensive approach is reverse strategy of aggressive approach. In this approach, thanos army retreats from the region with greatest density of avengers. Hence, thanos deploys in region with minimum density of avengers. Rest of the rules align with the aggressive approach.

D. Winning Condition

The deployment of avengers and thanos occurs synchronously one after the other. Now,stopping condition is achieved in two ways:

- One of the army completely eradicates other army from the battlefield while deployment are going on. At this point the eradicated army loses.
- Initial reserves of at least one of the army (A_0 or B_0) are completely depleted.At this point the battle ends and winner is to be decided.

Hence the victory is measured either by total territory control or by depletion of reserves. The magnitude of victory is given by :

$$x = \begin{cases} -1 & \rho_A = 0 \\ +1 & \rho_B = 0 \\ \frac{A-B}{A_0+B_0} & otherwise \end{cases} \quad [1]$$

Positive values denotes avengers victory and negative values denote Thanos victory.

E. Cellular automata model

The initial configuration of battle groud depends on two factors i.e. ρ_A and ρ_B.Variables are initialized as $L = 50, A_0 = B_0 = 50000, a = +1, +2, b = -1, -2$ and $\rho_A = 0.2, rho_B$.The initial configuration of battleground is as follows :

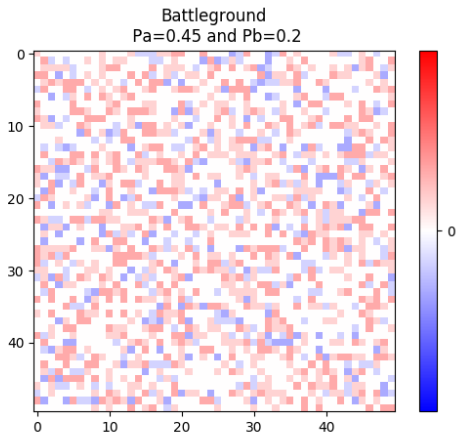


FIG. 1: Initial configuration of battleground for $\rho_A = 0.45$ and $\rho_B = 0.2$

In Fig. 1 the Avengers are depicted by red colour and Thanos army is depicted by blue colour.We can observe that initially both the armies are randomized according to their densities.
Now, the victory of army and final battleground configuration depends on the search range of attackers/Thanos (R).Let value of $R = 1$ i.e. each cell occupied by Thanos army initially can search in the neighbourhood of 3x3 matrix.

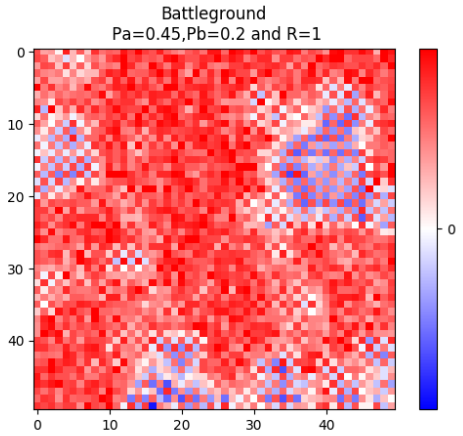


FIG. 2: Final Battleground configuration $\rho_A = 0.45$, $\rho_B = 0.2$ and $R = 1$. Avengers ran out of resources, Thanos army wins

In Fig 2 observation is that avengers are out of resources and Thanos army wins. We can see that the battleground's final configuration is full of avengers but by winning definition $x = \frac{A-B}{A_0+B_0}$ we get $x = \frac{-B}{A_0+B_0}$ as value of $A = 0$. Hence $x < 0$ denotes Thanos victory.
Now, changing value of R=10 we get the following result:

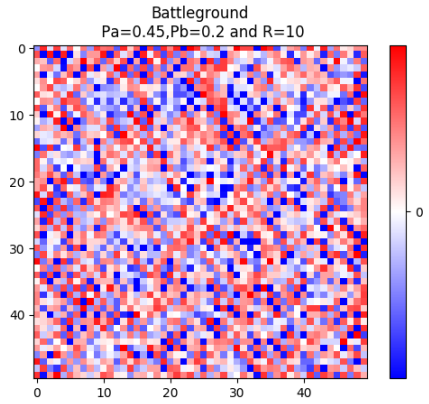


FIG. 3: Final Battleground configuration $\rho_A = 0.45$, $\rho_B = 0.2$ and $R = 10$. Avengers and Thanos ran out of resources at same time. Match Draws

In Fig. 3 we observe that avengers and thanos run out of resources at nearly same time and lattice has nearly same number of resources for both armies.Hence, match is drawn.
Now, changing the value of $R = 35$ and its effect are:

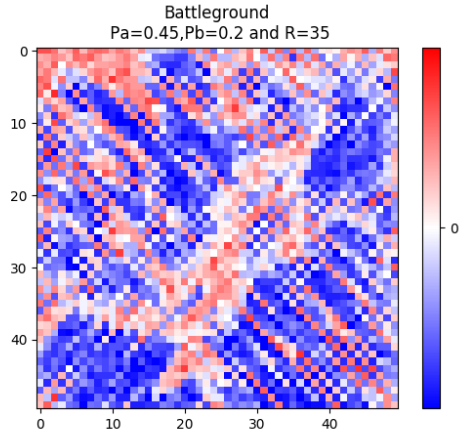


FIG. 4: Final Battleground configuration $\rho_A = 0.45$, $\rho_B = 0.2$,$R = 35$. Thanos army ran out of resources, Avengers army wins

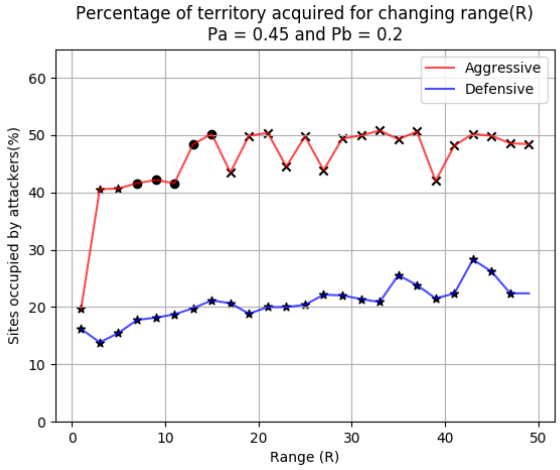
In Fig 4 observation is that Thanos army are out of resources and Avenger army wins. We can see that the battleground's final configuration is has maximum agents of Thanos but by winning definition $x = \frac{A-B}{A_0+B_0}$ we get $x = \frac{A}{A_0+B_0}$ as value of $B = 0$. Hence $x > 0$ denotes Avengers victory.

III. RESULTS

We found out that Thanos army(B) would depend on R such that it decays more rapidly when R have greater value.Hence, we can write a relation between B and R such that :

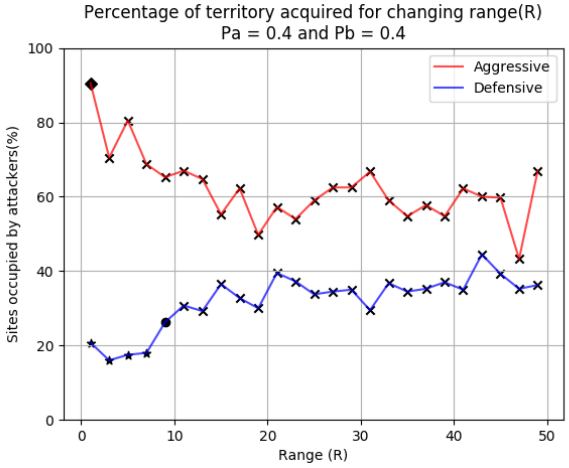
$$\therefore B = B_0 exp(-\alpha(\rho_A, \rho_B)R)[1]$$

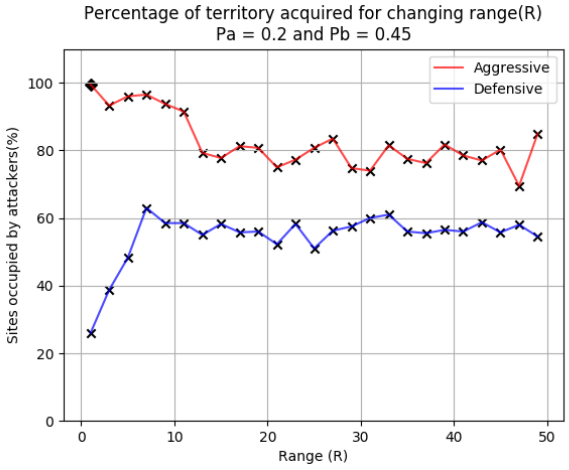
where α is some function of ρ_A and ρ_B. Hence, we can say that decay of Thanos reserves depends on (1) Search Range(R) (2) Initial Attack density (ρ_B) (3) Initial Defense density (ρ_A). Therefore we summarize the results determining territory acquired by Thanos army for varying values of R given different initial ρ_A,ρ_B and strategy.The results are as follows :



The symbol that are used in the Figures are:
♦- Thanos army have eradicated avengers, Thanos wins
×- Thanos army run out of resources, Avengers win
● - Both army run out of resources, Match draws
★ - Avengers army run out of resources, Thanos win.
We observe from our results that as when the search range(R) is small, the chances of winning of attackers is more and decreases as R increases. Larger R implies averaged local information over larger quadrant leading to less intelligent deployment as opposed to small R which implies precise information. Hence, values of R increases for fixed ρ_A, ρ_B victory of Thanos/attackers decreases.
Now, for decreasing ρ_A and increasing ρ_B and fixed value of R , we observe that chances of victory of Thanos decreases. Because high density (ρ_B) does not imply more territorial dominance, rather it implies less intelligent move as more density of attackers are deployed even if they are not required and hence leading to lose by running out of resources.

The defensive approach results in less area of the lattice controlled by the Thanos army but provides a better chance of dominating the Avengers. A defensive strategy works better in winning and in establishing territorial dominance in favor of attackers.





IV. CONCLUSION

We have modeled the conflict between intelligent attackers and defenders using agent based approach and with different strategies such as aggressive and defensive attack.From attackers point of view, outcome is victory if they have only some local knowledge and enough density of resources to deploy.From defenders point of view ,they should have less deployment density and should restrict communication of attackers.

[1] Alexandra Westley, *Study of simple land battles using agent-based modeling*, Int. J. Mod. Phys. B 31, (2017).

[2] L.Shanahan and S.Sen, Mod. Phy. Let. B25, 2279(2011).