War and Peace among Artificial Nations – a model and simulation based on a two-layered multi-agent system

Tatsuo Unemi[1], Yoshiaki Kaneko[1], and Ichiro Takahashi[2]

[1] Department of Information Systems Science,
[2] Department of Economics,
Soka University, Tangi-machi, Hachiōji, Tokyo 192-8577, JAPAN,
unemi@t.soka.ac.jp, ykaneko@intlab.soka.ac.jp, itak@soka.ac.jp

Abstract. This paper attempts to model the dynamics of war and peace in a virtual world to deepen our understanding why wars continue arising in spite of many peace keeping efforts. Land is modelled as a toroidal plain divided into square grid. Each nation consists of several villages that own a limited number of adjoining tiles of grids. A nation sometimes invades an adjacent village of another nation and occupies it. Inhabitants in each village consists of farmers, officers, and soldiers. Village can enlarge their territory by developing an empty tile, and can be independent from the nation they currently belong to. Each nation and village have their own *meme* for decision making that mutates when their successors inherit the strategies. In order to investigate what occurs in the virtual world we built a simulation system with a GUI that facilitates parameter set-up. The results displayed a typical phenomenon: repeated rise and fall of big nations. With other parameter settings, we also observed a period of equilibrium by a number of nations followed by a period of domination by one large ruling nation.

1 Introduction

War is barbarous and inhuman. Nothing is more cruel, nothing more tragic. . . . *Daisaku Ikeda*

War should be avoided in any situation. It destroys many things we wish to protect and keep. One of the naive questions asked is why we cannot prevent the foolish activities of war. Many persons have approached this issue from various standpoints such as social movement, religious organisation, statement propagation, international negotiation, contract and law, *et al.* The motivation behind building of a computational model of international relationship based on a multi-agent system, was to contribute in solving this serious problem and in understanding why the problem is difficult to solve. Recent researches on Artificial Life [1], Simulating Societies [2] and Artificial Societies [3] including authors' researches [4] on evolutionary ecology give important clues to our study. The current theory of evolution seems to deem this problem as insolvable since people

W. Banzhaf et al. (Eds.): ECAL 2003, LNAI 2801, pp. 146-153, 2003.

who employ peaceful strategies always suffers the domination of an aggressive nation with strong military power.

The following sections describe the model, some scenarios of simulation, suggestions for further studies, and concluding remarks.

2 Simplified World Model

Our simple model consists of a world involving two layers of organisations, *villages* and *nations*. We assumed a simple economy of production, storage, redistribution, and consumption of food, but we did not consider any other factors such as money, trading, technology development, and so on.

Land is fixed as the size of the toroidal surface divided into square grid. Each *tile* grid is either occupied by a village or is empty. Each village occupies one or more adjoining tiles. Each nation consists of one or more adjoining villages. More details are as follows.

2.1 Villages

Village is the unit of habitation in this model which includes its own population, land and food stock.

Population of each village increases with the growth rate, $\rho - 1$ every step if sufficient amount of food is available. Specifically, the population size of village i at step t is

$$P_{i,t} = \min(\lambda_p \rho P_{i,t-1}, F_a/\zeta), \tag{1}$$

where F_a is the amount of food available, ζ is the amount of food that is needed by one person per step, and λ_p is a random real number of fluctuation. People living in the villages have a choice of working as: a farmer, an officer, or a soldier. The farmers produce food, the officers work in public services such as food delivery, and soldiers fight against foreign nations according to decisions made by the government. The government of a nation decides the proportion of each type of worker as will be described later. Some portion of soldiers are killed in battle when the nation invades or is invaded by another. A village is ruined when its inhabitants disappear because of war or starvation.

The amount of food produced at a village in one step is given by

$$F_p = \lambda_f \min(\alpha P_f, \beta L), \tag{2}$$

where α is food production per farmer, P_f is the number of farmers, β is food production per tile of land, and L is the size of village in unit of tiles. λ_f denotes a random real number of fluctuation. A village stores the food produced for people in the next step. A fixed portion γ of food stock decays. Thus, the amount of food stock in village i at step t is

$$S_{i,t} = (1 - \gamma)S_{i,t-1} - \zeta P_{i,t-1} + F_{p,i,t} + F_{d,i,t} \tag{3}$$

where the second term in the right hand side is the amount consumed by the people, and F_d is the net amount of food delivered by national government as will be described later. The available food F_a in equation (1) is $\theta_a S$ where θ_a is a real value in the village *meme* of which range is $(0, 1]$. If $\theta_a = 0$, nobody can live in the village. If $\theta_a = 1$, the inhabitants soon disappear due to starvation because they consume the whole amount of food at once.

Each village attempts to expand its territory by developing an adjacent empty tile if the condition $\alpha P_f/\beta L > \theta_d$ is satisfied, where α, P_f, β and L are as used in equation (2), and θ_d is a threshold value in the village *meme*. The above equation implies that a village tries to expand itself when it has too many farmers, considering the size of its territory. When there is no empty tile around it, the trial has failed. The maximum number of tiles for one village was limited because a village was considered to be a unit of community where people can manage his or her resources effectively. Here, we denote the maximum number as $L_{\max}$. When the size L becomes greater than $L_{\max}$ after an expansion, a village is split into two of half sizes. Both of them inherit the meme from the original village, but one of the offspring is randomly chosen to be mutated.

2.2 Nations

Nation manages the food redistribution, and determines labour allocation into three types of workers. It is also the unit of military action, but its features are described later since it concerns the relationship between villages and nations.

Since each village is exposed to an independent random shock in food production. A nation can help stabilise food supply for villagers by delivering food from villages with good harvest to ones with bad harvest. The proportion of delivery from a village in nation k is

$$p_{d,k} = \phi_k \min(F^-_{r,k}/F^+_{r,k}, 1) \tag{4}$$

where ϕ_k is a real number obtained from the *meme* of the nation k with range $(0, 1]$, $F^+_{r,k}$ is the sum of surplus food over the nation k, and $F^-_{r,k}$ is the sum of deficiency. The amount of delivery F_d in equation (3) is

$$F_d = \begin{cases} p_{d,k} f_{r,i} & \text{if } f_{r,i} > 0 \\ p_{d,k}(F^+_{r,k}/F^-_{r,k}) f_{r,i} & \text{otherwise} \end{cases} \tag{5}$$

where $f_{r,i}$ is the surplus in village i, that is, $f_{r,i} = S_i - \zeta P_i$. If there is not enough surplus to cover the deficiency, the villages with surplus provide ϕ_k times of the whole of surplus, and the government delivers them to poor villages according to their deficiency. Rich villages are forced to behave altruistically, but this form of alliance is beneficial for them as well if ever they fall into deficiency.

A nation determines the allocation of labour into the three types of workers and the same decided-proportion is applied to all the villages it rules. Each nation employs officers and soldiers from villages. The total number of officers of a nation k is $P_{o,k} = aP_k + b$, where a and b are constant values and P_k is the population size of the nation k. The number of soldiers determines the military power of the nation. In this model, each national government prefers keeping the number of soldiers as follows.

$$\hat{P}_{s,k} = \frac{w_1\sigma_1 \max_{j\in N_k} P_{s,j} + w_2\sigma_2 \min_{j\in N_k} P_{s,j} + w_3\sigma_3\bar{P}_{s,k}}{w_1 + w_2 + w_3} \tag{6}$$

$$\bar{P}_{s,k} = P_k - P_{o,k} - \frac{\zeta P_k - S_k}{\alpha} \tag{7}$$

where N_k is the set of neighbour nations of k, $w.$ and $\sigma.$ are real values in the nation *meme*. Three factors are considered in deciding on the scale of military power: defence against its strongest neighbour, invasion of its weakest neighbour, and capacity of support. The terms from left to right of the numerator in equation (6) corresponds to these factors accordingly. $\sigma.$s are biases and $w.$s are weights. Their ranges are $\sigma_1 \in [0, 1.5], \sigma_2 \in [0, 2.5], \sigma_3 \in [0, 1]$, and $w. \in [0, 1]$. In each step, national government employs officers from the villages, aims at keeping the ideal number of soldiers, and then allocates the rest of the population as farmers. If $\hat{P}_{s,k} > P_k - P_{o,k}$, that is, if it fails to keep the target number of soldiers, all of the people other than officers are employed as the soldiers, and the nation has no farmers.

2.3 Independence and move

A village can choose either to become independent or change the nation it belongs to. The index of *richness*, defined as the amount of food stock per inhabitant $R_k = S_k/P_k$, is assumed to be used as the criterion in deciding which nation is better to belong to. In each step, each village computes the richness indices of its adjacent neighbouring nations and compares them with the nation it currently belongs to. Taking the expected richness after independence into consideration, it decides the choice of its association state. It chooses independence or moves to an adjacent nation if it can improve the current situation. This action taken by a village will not be interfered by the nations unless the village is under a target of invasion. The meme of the newly independent nation is a mutant of the original one.

2.4 Invasion and occupation

When the nation has military power, it tries with probability ψ_k to find a victim from adjacent villages beyond the national border. ψ_k is a real number in $[0, 1]$ in the nation *meme*. The nation invades the richest village of a weak nation to occupy it. The criteria of weakness of victim nation is defined as $P_{s,v}/P_{s,k} < \mu_k$, where $P_{s,v}$ is the number of soldiers of victim nation, $P_{s,k}$ is the number of soldiers of invading nation, and μ_k is a real number in the range $[0.2, 0.8]$ of the nation *meme*. The winning probability for the offending nation is

$$P(o) = x^2/(1 + x^2), \quad (x = \nu P_{s,k}/P_{s,v}), \tag{8}$$

where ν is a constant in the range $(0, 1]$ representing how advantageous an invader is. The above equation guarantees that the more soldiers are provided, the more there is of the probability to win. Moreover, the side defending the target village is more likely to succeed when both sides have the same scale of military power. After a battle, some portion of soldiers are killed. In this model, the percentage of war casualties in each nation is calculated independently as the probability distribution of triangle shape, where its peak is achieved at the centre value of the number of soldiers of a weaker nation.

2.5 Geographical constraint

Because we assume all the villages belonging to a nation adjoin to each other, a nation can invade only an adjacent village, and a village can choose to belong only to the adjacent nations. This geographical constraint also implies that a nation is sometimes separated into multiple nations after a village becomes independent, moves to another nation, or falls into ruins. All of these separated nations inherit the same meme from the original nation, but they mutate independently from each other after separation.

2.6 Inheritance and mutation of meme

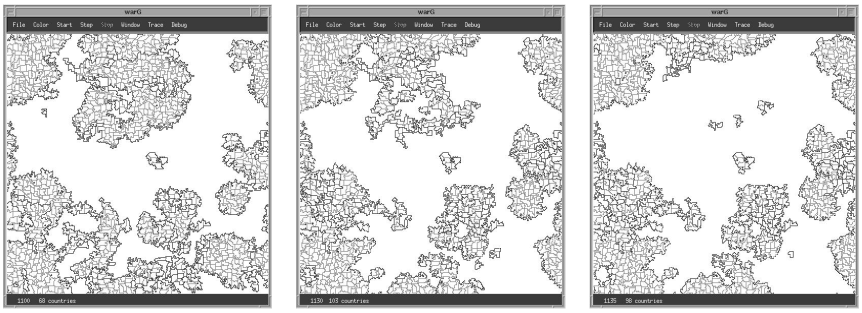
As described above, some parameters for decision making are encoded in the memes in villages and nations. The values of all of these parameters are real numbers, though their ranges are different. In the current implementation, each parameter is encoded by eight bits byte representing an unsigned integer, which is linearly transformed onto the specific range. The mutation is done by adding a random integer with Gaussian distribution $N(0, \sigma_m)$ to the original byte and adjusting the value range from 0 to 255. It is forced to be 0 or 255 if the value is less than 0 or greater than 255, respectively. In addition to the split cases of independence and separation, the memes of any villages and nations mutate at an interval of various steps. The number of steps in one interval is also encoded on the meme. In this model, the interval could be interpreted as the duration of a King's reign or President's term.

3 Some scenarios

We examined several combinations of parameter settings and initial conditions in the simulation of a numerous number of steps and trials, under 256×256 tiles torus world. Starting from 256 randomly arranged nations, each of which owns four villages of ten tiles, we observed the following two types of typical scenarios.

3.1 Rise, division, then ruin

One typical scenario was repetition of rise, division, and then ruin of relatively big nations. Figure 1 shows a typical process of division and ruin. The parameter



Step 1100 Step 1130 Step 1135

Fig. 1. A typical process of division and ruin of a big nation. The small area surrounded by grey border is a village, and the large area surrounded by black border is a nation. A relatively big nation in Step 1100 at upper middle position was separated into small nations before Step 1130, and then fell in ruin in Step 1135.

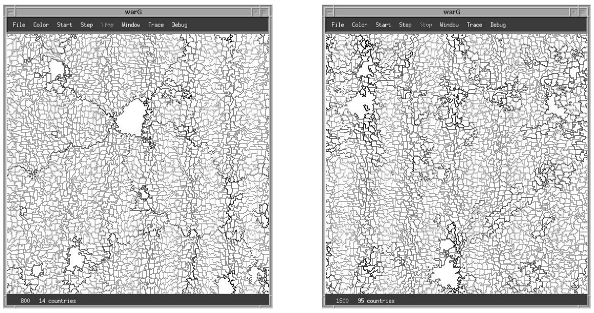
settings are $\rho = 1.1, \alpha = 2, \beta = 100, \gamma = 0.05, \zeta = 1, L_{\max} = 50\text{tiles}, P_{o,k} = 0.2P_k + 70, \nu = 0.5, \sigma_m = 25.5$, and $\lambda_p, \lambda_f = N(1, 0.05)$.

Once the government makes an occasional mistake because of mutation or neighbour nations' change, some relatively rich villages becomes independent from the nation and/or some poor villages disappear. This type of event causes the separation of the nation into a number of smaller nations. In this model, it is difficult for a small nation adjacent to a big one to keep being independent because it has to have military power strong enough to defend against the adjacent big nation. Inevitably, a small nation is invaded and occupied by another big nation, or falls under starvation because it allocated too many of its inhabitants as soldiers, sacrificing food production.

3.2 Equilibrium and domination

Making the scale of mutation smaller, we can observe a more stable domination of land by a number of nations. If there were no mutations and no fluctuations, the world would be consisting of a number of stable nations and would never change. Figure 2 shows an example pattern of the case of $\sigma_m = 12$. The left figure is a type of equilibrium. But this situation does not remain the same for a long time because of small but nonetheless existing mutation. The right side of the figure shows a pattern of the later step. The nations in the previous world falls into ruin and one super power dominates almost the entire world.

The left plots of figure 3 shows how the number of wars in each step changes over time in the case of Figure 2. Between approximately 100th and 500th steps, a large number of small nations aggressively fight against each other. After this "war age," the world shifts to relatively stable state of equilibrium with a number of rivalling nations, in which wars are relatively suppressed from 600th to 1300th step. But this situation breaks up before 1400th step.



Step 800 Step 1600

Fig. 2. Patterns of equilibrium and domination under the lower rate of mutation.

In terms of the frequencies of war, it seems better to be in equilibrium than under one nation's domination. But the right plots of figure 3 suggests that it is not true from another point of view. It shows the proportion of war casualties for population in each step. The scale of war casualties during the equilibrium is not smaller than those during the earlier "war age." It once shrinks at around 1100th step, but literally exploded at 1300th step, when more than 22% of people were killed by war. We should notice that the number of casualties becomes very small after this massacre. This low casualties is resulted from the small portion of soldiers in the dominant nation facing practically no rivalry.

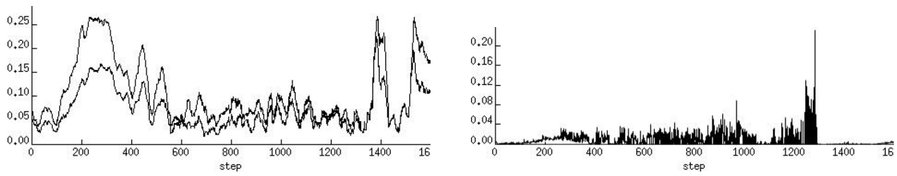


Fig. 3. Left: The moving average (window size = 20 steps) of the times of wars per nation in each step. The lower lines indicate the times of successful occupation by invaders. Right: The proportion of war casualties in each step.

4 Next step

The model described above lacks many features, and we can improve it by having more appropriate similarities with real history. The items listed below are the candidates we will implement in the near future.

1. *Upper layer over nations*: Any type of coalition or alliance among nations can provide stronger influence in both peace keeping and domination. More flexible organisation of layers should be considered.

2. *Lower layer under villages*: Social movements in democratic society against war are mainly motivated by the emotion of hating inhuman behaviour. It is important to consider the dynamics in the bottom layer, organised by people, to consider whether democracy is effective to suppress wars.
3. *Distribution of troops*: The reason why a small nation hardly remains in this model is that a big nation can fight with all of soldiers it employed from widely distributed villages. This is not realistic. The cost of deploying troops and the strategy of distributed dispatch of troops should be considered.
4. *Nonuniform distribution of fertility*: Conflict among nations sometimes arises because of limited natural resources. Nonuniform distribution of fertility of land tiles can capture this situation.
5. *Similarity and possession norms*: Riolo *et al* [5] showed that similarity among agents can lead to the emergence of co-operation. Flentge *et al* [6] demonstrated that conflicts become less likely to occur as the possession norms emerges. We will incorporate these important features into the model.

5 Conclusion

We constructed a world model of nations, in a form of two-layered multi-agent system, which endogenously choose the strength of military forces. We demonstrated two typical processes of the virtual world: repetition of rise, division and ruin of nations; a type of equilibrium among a number of nations followed by a period of domination by one huge nation. We examined these different periods of the world in terms of the frequency of wars and the scale of casualties.

Through the repeated experimental simulation, we obtained expectation for this approach to be promising and useful to understand the dynamics of international relationships, though it is necessary to extend to a more realistic model by adding features including ones listed in the previous section.

By modifying some features such as geographical constraints, this approach seems to be applicable not only to international issues but also to economic battles among companies in a market.

The authors hope the usage of this particular system can contribute to realising a more peaceful world.

References

1. Langton, C. G., ed.: Artificial life. Addison-Wesley (1989)
2. Gilbert, N., Doran, J., ed: Simulating societies, UCL Press, London (1994)
3. Epstein, J. M., Axtell, R.: Growing artificial societies. MIT Press (1996)
4. Unemi, T.: Should seeds fly or not? Proc. of the Seventh International Conference on Artificial Life. (2000) 253–259
5. Riolo, R. L., Cohen, M. D., Axelrod, R.: Evolution of cooperation without reciprocity, Nature **414** (2001) 441–443
6. Flentge, F., Polani, D., Uthmann, T.: Modelling the emergence of possession norms using memes, Journal of Artificial Societies and Social Simulation **3** (2001) http://www.soc.surrey.ac.uk/JASSS/4/4/3.html