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Using Spatial Strategies to Model Agents' Commitments for a Protocol Formation

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Abstract: In spatial strategies of a spatial prisoner's dilemma (Ishida and Mori '05), it is possible to involve not only geographical configuration of countries but many other relation such as economical relation, historical relation, military relation and so on if they can be expressed by a network. This paper explores the possibility of modeling the agents' commitments using the spatial strategies. Several types of spatiotemporal strategies are discussed in a context of protocol formation in the international communities.

Keywords**:** spatial prisoner's dilemma, spatial strategy, international politics, protocol formation

I. INTRODUCTION

The game theoretical analysis of international problems has received increasing attention in recent years. This paper tries to model the organizing process in a protocol formation using different strategies of a spatial prisoner's dilemma (SPD), as observed in organization of international protocols and agreements such as protocols in the environment problem, free trade agreements, the nuclear non-proliferation treaty and so on. Nowadays, there appear an increasing number of international protocols and agreements on greenhouse gases emission, global warming, nuclear weapons and so on which are not agreed and cooperated by all countries. On the gases emission for example, since the impact of a country on the global pollution level is rather small, each country is reluctant to reduce the emission. Therefore, the reluctant structure is similar to a SPD. The similarity can be conspicuous when cooperation/defection in SPD is corresponded to agreeing/rejecting the protocol.

In this paper, we use a two dimensional lattice to represent spatial circumstances such as geographical configuration of countries, economic circumstance, historical background, military position and so on. On the lattice, we explored the possibility of modeling the agents' commitments using the spatial strategies. A few typical spatial strategies are discussed in a context of protocol formation in international communities.

II. BASIC MODEL

1. The Prisoner's dilemma

Prisoner's dilemma (PD) is a game played by two players with two actions: cooperation C, or defection D (Table 1). If both cooperate, they gain payoff ***R*** (reward) whereas if both defect, they gain payoff ***P*** (punishment) lower than ***R***. But if one player defects when the adversary cooperates, then the defector gains payoff ***T*** (temptation) which is higher than ***R*,** whereas the cooperator's payoff ***S*** (sucker) is the smallest (1). When one player defects, it always gains a higher payoff than that when it cooperates. However, if both players defect, they gain a lower payoff than that when they both cooperate.

In iterated prisoner's dilemma (IPD), PD is carried out repeatedly where double ***R*** higher than ***T*** plus ***S*** (2). Players with possibly distinct strategies are placed at each cell in a lattice. The strategy will determine the next action based on a spatial configuration of C and D in the neighborhood. We called the strategies as spatial strategies (Ishida and Mori '05) in SPD.

$$T > R > P > S \tag{1}$$

$$2R > T + S \tag{2}$$

Table 1. The payoff matrix of the PD game

		Player 2	
		C	*D*
Player 1	*C*	***R, R***	***S, T***
	D	***T, S***	***P, P***

2. Modeling

We first present a model of an SPD in which $N \times N$ - countries (agents) as players can either cooperate, C or defect, D in a square lattice space with the size $N \times N$. All the countries are divided into two classes: q majors and the rest $N \times N$ -q minors. They are placed at each lattice. Each player interacts with n neighbors (the Moore neighborhood is used, hence eight neighbors). We use the periodic boundary condition. Each country has its own spatial strategy and action. Spatial strategy determines the next action depending upon the spatial pattern of actions in the neighbors. Each country gains the payoff corresponding to their actions after they play the PD game with the neighbors.

Major countries act as major powers. They have a power of influence to make minor countries follow. In this model, the major countries use either All-C (C major) or All-D (D major), and have a higher weight w ($1 \leq w \leq 50$) than minors.

Minor countries have a spatial strategy of ***k***-D (See the next section 3), which determines the next actions based on the neighbors' actions.

Table 2 lists the payoff matrix used. The parameter ***b*** is set to be a minimal value that allows All-D to expand. Fig.1 illustrates a calculation on how to define the parameter [2].

Table 2. The payoff matrix

		Adversary	
		C	*D*
Country	*C*	$R=1$	$S=0$
	D	$T=b$	$P=0$

The score of each country is calculated by summing up all the scores received from PD game with its neighbors (including the self [2]). After ***s*** (strategy update cycle) steps of interactions with the neighbors, the minor country updates its strategy to the strategy that earned the highest score in the neighbors. The strategy update cycle ***s*** is set to be 1 throughout this paper.

3. *k*-D Strategies

The minor countries take ***k***-D strategies to make decisions based on the spatial pattern of actions (C/D) in

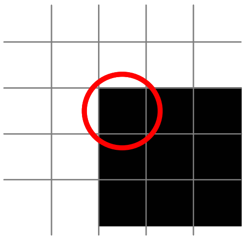


Fig.1 How to calculate the parameter b. C and D are indicated as white and black cells respectively. For All-D in the corner (indicated by the circle) to gain the profit higher than the cooperators, b must satisfy 5b > 9 since the highest payoff of the cooperators is 9.

the neighbors [1, 2]. The integer ***k*** (of ***k***-D) indicates the spatial version of the generosity (how many D actions in the neighbor are tolerated). The ***k***-D strategy determines the next action based on the number of D actions in the neighbor. The ***k***-D strategy will take D if $l \geq k$ where ***l*** is the normalized and weighted sum (with weight ***w***) of Ds in the neighbor excluding the self, and will take C otherwise. Let ***g*** be the number of majors with All-D strategy, hence with D action, and ***h*** be the number of minors with D action then the normalized and weighted sum ***l*** can be expressed as follows:

$$l = \frac{gw + h}{q(w-1)+n} n \tag{1}$$

where ***n*** is the number of neighbors and ***q*** is the number of major countries.

Fig. 2 illustrates example of the action update with a ***k***-D strategy. The country (gray) changes its action to C because the normalized weight ***l*** does not exceed ***k***.

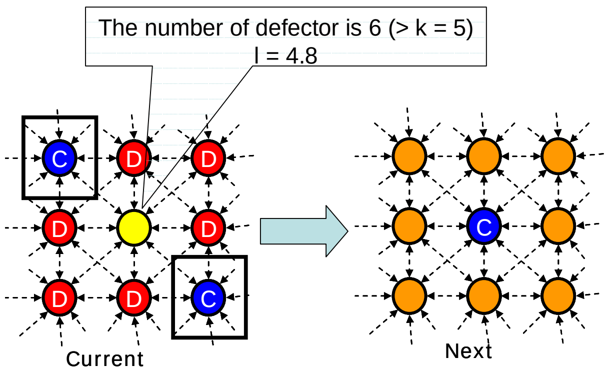


Fig.2. An example of an action update of a *k*-D strategy where *k*=5, *l*=4.8, and weight *w*=2. The black rectangle indicates a major country.

III. SIMULATIONS

Simulations are conducted with the parameters listed in Table 3. We investigate if the protocol formation (C cluster) is observed when minor countries surround the major countries. We are interested to see if the existence of major countries, those with the All-C strategy (C major) in particular, can enhance the formation of C-cluster or not.

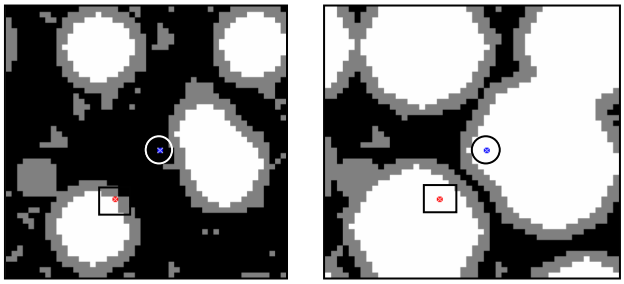
Table 3. List of parameters for simulations

Name	Value
Number of countries *N* (Lattice size)	50×50
Generosity of *k*-D strategies	$1 \le k \le 9$
Number of majors *q*	0,1,5,10,30,50
Ratio of All-C major and All-D	1:1
Weight *w* of major	1,2,5,10,20,30,50
Bias *b* for defection in the payoff matrix in Table 2	1.81
Time steps (*t*)	100
Number of trials	10

In the interaction between All-D vs. ***k***-D rather than All-D vs. All-C (as in Nowak-May's SPD), the clusters of ***k***-D form a membrane (gray) of action D protecting the inner cluster of action C (white). The membrane formation occurs as in our simulation within a certain parameter scope of ***k*** (spatial generosity) and ***b*** [2].

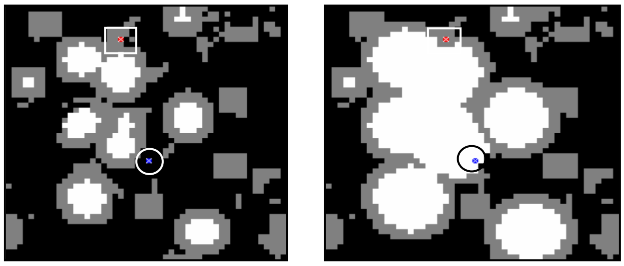
Fig. 3 shows an example of snapshots of the cases where the membrane is formed with both C major country and D major country involved. The membranes of C clusters are not broken in Fig. 3(b) even if it expands through the C major (indicated by the circle). It means that the action (power) of the major country does not affect the neighbors, because the major's effect is almost the same as those with the minors (with the ***k***-D strategies) when the weight ***w*** is low enough. On the other hand, the membrane of C clusters (Fig. 4(b)) is broken when it expanded through the C major country (indicated by the circle). The C major country made the minors in the corner select the action C, because the power of the major country is influential with the high weight ***w***, hence making the normalized and weighted sum relatively small. The D major country made the surrounding minors with the ***k***-D strategy select D action, because they are affected by the power of the major when the weight ***w*** is high enough.

When the weight ***w*** is low enough, D major countries (indicated by the rectangle) can exploit their neighbors (Fig. 3(b)), because the neighbors are



(a) Steps = 12 (b) Steps = 21

Fig.3. Two snapshots showing that membranes are protecting C-clusters with the 6-D strategy where and number of major is 1 for C and D major and weight is 2. Black (white) and gray cells indicate defector (cooperator) and defector of k-D, respectively. Cells in the circle (rectangle) indicate D (C) major.



(a) Steps = 6 (b) Steps = 12

Fig.4. A snapshot of breaking membrane where number of major is 1 and weight is 50

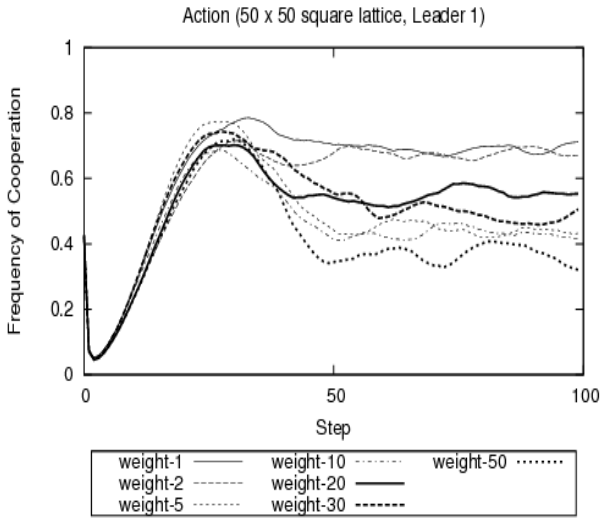
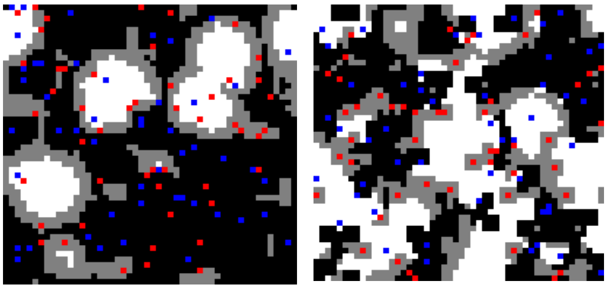


Fig.5. Frequency of cooperators with one C major country and one D major country.



(a) Weight = 2 (b) Weight = 50

Fig.6. A comparison of membrane formation when the weight varies and the number of major is set to be 50.

cooperators. When the weight ***w*** is high enough, however, the neighbors of D major countries exploit their C neighbors, while the D major countries themselves cannot.

Fig. 5 shows the time evolution of cooperator's frequency when the weight ***w*** varies with one C major country and one D major county. The fraction of cooperators becomes larger as the weight ***w*** becomes lower. The membrane can grow without being affected by the majors when the weight is low (Fig. 6(a)). When the weight is high enough, however (as in Fig. 6(b)), the membrane is broken by the D major countries, because the power D major country is strong enough, hence breaching the membrane. Fig. 6 shows a snapshot with weight 2 and that with weight 50, corresponding to those weights in Fig. 5.

IV. DISCUSSION

In the real world, the countries confront to the situation that they have to agree/reject being affected by major countries in the neighbor. Computer simulations revealed that the minors are affected by their neighbor majors when they have enough power. We observed the minor countries implementing the spatial strategy *k*-D can form C-clusters by being protected by a membrane when the influence of major is low enough. However, the fraction of cooperators decreases as the weight of the majors increases (Fig.5). In the problem of organizing international protocols such as Kyoto Protocol, the number of agreed countries tends to be low possibly due to influential majors, or due to too low benefit in the payoff matrix.

V. CONCLUSIONS

This paper applied Prisoner's Dilemma (PD) to the problem of international cooperation in organizing protocols and agreements such as protocols in environment problems, free trade agreements, and the nuclear non-proliferation treaty and so on. We used a spatial strategy *k*-D for minors and the fixed strategy All-C or All-D for majors. The influence of countries is tuned by the weight parameter in counting the number of actions in the neighbor.

Computer simulations with the model revealed that there are cases when the existence of cooperating major countries could hamper the formation of cooperative clusters.

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