Tuning of the Update Timing Will Stop the Defector Invasion in the Spatial Game Theory

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Abstract: Since the defectors tend to survive in the Spatial prisoner's dilemma, many studies have proposed models for the purpose of survivals of cooperators. But many of those models are not realistic. Therefore, in this study, we proposed a model that considered the player's decision-making time based on previous research. In the proposed model, the defectors decrease the probability of the strategy update while the cooperators increase the probability of the strategy update. In this paper, we investigate the defector density and the spatial distribution by setting two different system sizes: 50×50 and 200×200. Since the results were very similar to each system size, we found that the proposal model was not affected by the system size. Furthermore, ever if the payoff parameter regarding a defector vs. a cooperator increased, the defector density did not increase rapidly, which was against the conventional model. We compared the spatial distribution of the proposal model with the conventional model and found that cooperators were widely maintained in the proposal model while they were partially maintained in the conventional model. Thus, the proposed model that introduces decision-making times of players is a realistic model and contributes to the survival of cooperators.

1 INTRODUCTION

Humans demonstrates cooperative behaviours that facilitate the prosperity of human populations (Maynard Smith and Price, 1973). Cooperators can build a win-win relationship within a group of people having similar characteristics. Among selfish people however, cooperators may be exploited. Nonetheless, selfish behaviors are also one of the characteristics of humans. The game theory presents how selfish/cooperative behaviours are evolved in population systems (Nowak and May, 1992, Doebeli and Hauert, 2005, 2022, Marko et al. 2022). In the basic game theory, players select one strategy from two strategies. Defectors can win alone within a group of cooperators. However, defectors get almost nothing when facing with people having the same strategy. On the other hand, cooperators can be mutually benefitable while they are deprived of profits when facing people having the against strategy. In the classical spatial game theory, cooperators appeared to be extinct in some situations (Hauert and Doebeli, 2005, Szabó and Toké, 1998). To solve this issue, a lot of studies have focused on the evolution of cooperators. Some of them have considered the importance of external disturbances while others have considered the evolution of link weights and so on (Szolnoki and Perc, 2014, Qin et al. 2018, Shen et al. 2018).

In this paper, we develop a spatial prisoner's dilemma (PD) model by considering a relationship between players' decision time and the timing of the strategy-update. Since some of previous models do not consider the actual actions found in humans, we refer to a study reporting that human subjects switched their cooperative behaviours with selfish behaviours according to the thinking time (Capraro, 2017). In our model, individual players have a fixed time interval for the strategy update. The conventional model only considers the rules of battle and strategy update in Prisoner's Dilemma. They sometimes modulate that timing based on their strategy. As a result, we found that the population system in our model confirmed the survival of cooperators. Interestingly, we could not find any advantages of cooperators' survival if players held a given time interval and did not coordinate it. Thus, the coordination of the update timing can be related

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to the propagation of cooperators/defectors in the populations.

2 METHODS

2.1 Simulation Environments

We introduced players on two-dimensional square lattice having 200×200 or 50×50 system size. Each player was set on individual cells. One of two strategies (defector (D) or cooperator (C) was assigned to individual players. Payoff can be *R*=1, *T*=*b*, *S*=*P*=0 satisfying *T*>*R*>*P*>*S*. Parameter b that determines T can be set to $1 < b < 2$ (Nowak and May, 1992). In that paper, *S*=*P* is applied, as *P* is a positive number and does not lose generality when *P* is less than 1.

As the boundary condition, we adopted the periodic boundary condition. Von-Neumann neighbourhood was used for players' interaction. Each simulation experiment lasted for 500-time steps.

2.2 SPD Model

Here, we defined the spatial prisoner's dilemma (SPD) model as the control model. In the SPD model, two sub-models exist in each time iteration. In the first sub-model, individual players earn scores by interacting with the neighbouring players. More strictly, each player plays against all neighbouring players who located above, below, right, and left of the player and earns scores based on the payoff matrix.

In the second sub-models, each player updates its strategy by comparing its earned scores with the neighbouring players' scores. Players replace their strategy with the new one's strategy that has the highest score among neighbouring. The strategy update will stop for the player if more than two players among itself and neighbouring players have the same highest scores but have different strategies with each other.

The classical SPD has a problem that defectors increase as the parameter b increases after the system reaches a steady state.

2.3 Proposed Model

Here, we proposed two different models. One is the Interval PD (IPD) model. The other one is the Update-Modification PD model. Both of two models are based on the cognitive experiment using the human subjects where subjects presented various thinking time, which depended on whether they behaved like a defector or not (Capraro, 2017).

In the report, researchers found that people were more likely to choose the selfish action when having much thinking time. On the other hands, people were more likely to choose the cooperative action when having short time.

2.3.1 IPD Model

In the IPD model, individual players have a unique variable named as *interval*. The variable *interval* is the time interval between two consecutive strategy updates. Each player is randomly given a different random natural value of *interval*, and the value is fixed at the end of each trial. The minimum value is 1, the maximum value is p, and p can be set as a parameter. Thus, players have a chance to update their strategy every *interval* time steps.

2.3.2 UMPD Model

We modified the IPD model and named the modified model as the Update-Modification Prisoner's Dilemma (UMPD) model.

The featuring point of this model is that we introduced a probability into the strategy update event. Therefore, players in this model do not always have a chance to update their strategy every *interval* time steps. The probability is implemented using the variable *interval*.

If the strategy of player is D (defector) at the strategy-update timing, the strategy can be updated with the following probability.

$$1 \;/\; \text{interval} \quad (1)$$

On the other hand, if own strategy of player is C (cooperator) at the strategy-updated strategy timing, the strategy can be updated with the following probability.

$$1 - (1 \;/\; \text{interval}) \quad (2)$$

These two rules are based on the fact that the human subjects present long/short thinking time when they behave like a defector/cooperator. Therefore, players in this model tend to maintain the current strategy using the variable *interval*. At the same time however, the probability is dependent on the current strategy of players.

3 RESULTS

The initial distribution probability r for defectors was fixed at 0.5. It means that density of defector and cooperator were equal. We set 1000-time steps as one trial. Parameter b was set to $1 < b < 2$. The maximum interval p was fixed at 3. It means that each player had an interval randomly from three interval values: $interval = 1{,}2$ and 3. The value of *interval* was assigned to individual players at start of each trial. We set two different system sizes. One was 50×50. The other one was 200×200. We examine the effect of changing system size of the proposal model.

3.1 Invasion of Defectors

In this subsection, we checked the relationship between parameter b and the defector density. Here, the average density of defectors was calculated using the defector density at the end of trial ($t = 1000$) over 10 trials.

First, we show results using 50×50 system. According to Figure 1, which shows the relationship between parameter b and the average defector density for three models, model having the largest defector density is the UMPD model in $1 < b < 1.5$. But as the parameter increased, the UMPD model performed better than other two models since the defector density did not become large in the UMPD model while the defector density increased sharply in the other models.

Next, we show results using 200×200 system size. Figure 2 demonstrates the relationship between parameter b and the defector density. Consequently, the UMPD model did not perform well in the $1 < b < 1.5$. However, as the parameter increased, the UMPD model again performed better than other models.

We found that there was no difference regarding the defector density and its relationship with the parameter b between 50×50 system size and 200×200 system size. Therefore, the UMPD model is a flexible model regardless of the system size.

3.2 Spatial Distribution

We also checked the spatial distribution. Here, we present the defector/cooperator distributions using the UMPD model and the SPD model at $t = 1$, 10, 20 and 30. Parameter b was fixed to 1.9 for the UMPD model.

First, Figure 3 shows the spatial distribution of the SPD model. Cooperators partially survive while defector occupies most of space at $t = 10$. Then, each cooperator seems to spread vertically and horizontally around the certain cooperators. After that, some cooperators additionally spread vertically and horizontally as a time goes on. However, cooperators do not appear in other places. Consequently, cooperators can be maintained partially.

Next, Figure 4 shows the spatial distribution of the UMPD model. Cooperators widely survive at $t = 10$, which is contrary to the case of SPD model. After that, there is no significant change in the spatial distribution.

Therefore, cooperators can be survived easier in the UMPD model than the SPD model.

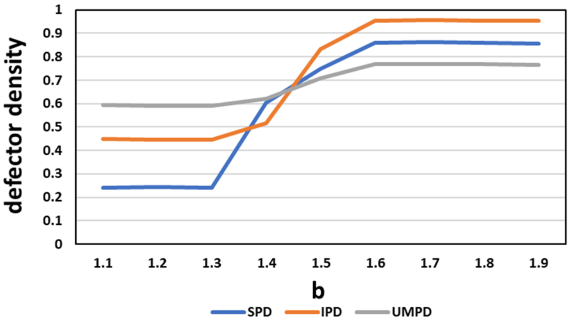

Figure 1: The defector density in the three models (the system size: 50×50). $p = 3$.

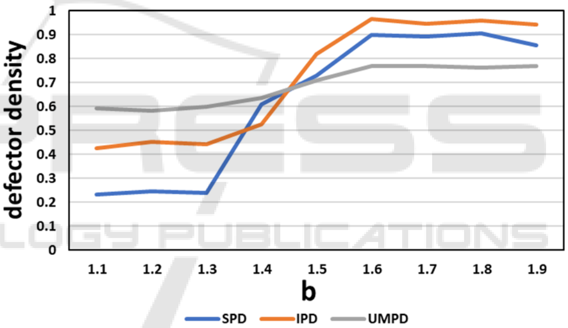

Figure 2: The defector density in the three models (the system size: 200×200). $p = 3$.

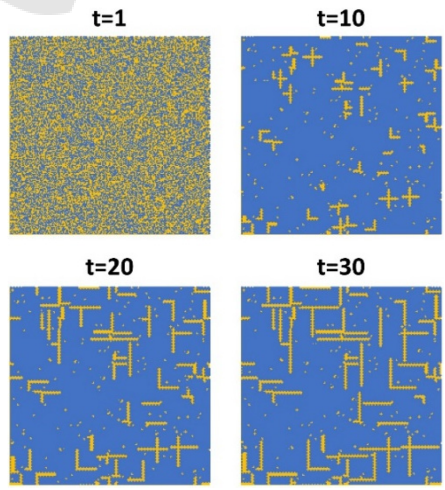

Figure 3: Spatial distribution of the SPD model. Blue: D (defector), Yellow: C (cooperators).

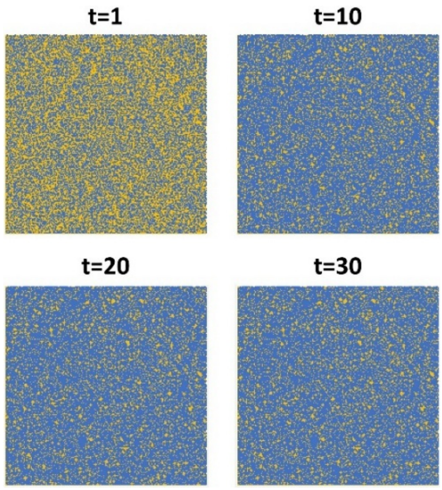

Figure 4: Spatial distribution of the UMPD model. Blue: D (defector), Yellow: C (cooperators).

4 CONCLUSIONS

In this paper, we proposed the UMPD model for the purpose of maintaining the cooperator. In the proposed model, decision-making time for strategy update is probabilistically introduced into the SPD model. Consequently, the UMPD model is easier to maintain the cooperator than the conventional model. In the SPD model, the defector density tends to increase as the parameter *b* increases. On the other hands, in the UMPD model, the defector density is unlikely to be increased as the parameter *b* increases. Therefore, it is considered that the model is less affected by the parameter than conventional model. We were also able to get similar results even after the system size replacement.

According to the previous research by V.Caprero (2017), the longer human subjects have thinking time, the easier human subjects behave selfishly. Similarly, human subjects behave cooperatively if they have short thinking time. Similar effects were introduced on our model. Therefore, we introduced realistic assumptions in the model. As a result, players having the cooperative strategy tend to be maintained if they have relatively short thinking time. This is considered that the cooperator density stabilized by introducing the probability of strategy update that (1 / interval) and (1 - (1 / interval)) into the conventional model.

Since some players do not update their strategies when interval = 1, we added a rule to change the value of interval after a strategy update was made. However, since the result was the same as before the change, it is considered to be less affected by the value of interval = 1. Detailed results will appear in another paper (Takahara and Sakiyama, 2023).

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