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# Properties of Prisoner's Dilemma Game Based on Genetic Algorithm*

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**Abstract:** Evolutionary games are widely studied in the fields of biology, sociology, economics and informatics. People's interests focus on how cooperation emerged in a system that individuals are selfish. We studied the iterated Prisoner's Dilemma Game evolved on BA network with genetic algorithm. Nodes in network could remember the game historical strategies and coded into gene. We show that memory length has gentle effect on cooperation level, and that some characteristic genes and frequently used genes emerge after some generations. We also find that cooperate strategy distributed on different degree-nodes equably. These findings give new perspectives to the illustration of cooperation behavior in biological group and society.

**Key Words:** Evolutionary Game, Scale-free Network, Genetic Algorithm

## 1 INTRODUCTION

In human society and nature, selfish individuals in a population producing cooperation are common pheno menon. Thus, understanding the emergence and persistence of cooperative behavior among selfish individuals becomes a central problem [1-3]. Many scientists from different communities resort to the game theory as a common framework to investigate this cooperative dilemma [4-11]. Prisoner's dilemma game (PDG) is a classic model of game theory. In PDG, two players simultaneously decide whether to cooperate or defect. They both receive R upon mutual cooperation and P upon mutual defection. A defector exploiting a cooperator gets payoff T and the exploited cooperator receives S, such that T >R> P>S.

Nowak and Sigmund [5] have studied evolutionary games on 2-dimensional grid. They discovered that for prisoner's dilemma, space structure can promote cooperation. Axelrod [9] supposed that individual can memory the last 3 games, and used genetic algorithm (GA) to study individuals with memory evolved in well mixed populations. Lin [10] studied GA game on complex network. Our work based on [9, 10], we investigate the effect of memory length to cooperation, find characteristic genes, frequently used genes and strategy's degree-distribution.

## 2 MODEL

We make up a scale-free network with BA model, and use genetic algorithm to study how individuals at complex network can evolve cooperation with PDG. Every node in the network games with directly connected nodes and can remember the last L games. For example, if L=3, we use bit 1 to indicate cooperation, and use bit 0 to indicate defection. So we can use 2L bits to indicate the last L games. For example, if L=3, Hij=100111 indicate the last 3 games history of node i and node j: i cooperated, j defected, i defected, j cooperated, i cooperated, j cooperated. 3 iterated games have 64 possible different histories: 000000, 000001, 000010, ⋯, 111111. These bit-strings can be converted into decimal number from 0 (000000) to 63 (1111111), which means 64 different possible histories. For each history, nodes can take a strategy (defection 0 or cooperation 1) for next game. Then we get a 64-bit chromosome, each gene on the chromosome can be 1 or 0, indicating the individual's strategy according to a particular history. For example, node i has a chromosome Ci=100110111⋯, the first gene (No.0) means a game history 000000, it's value is 1 means the node will cooperate next game; the second gene(No.1) means a game history 000001, it's value is 0 means the node will defect next game, and so on.

At beginning, for memory length L, individuals randomly initialize chromosomes (length $2^{2L}$) with all genes set to 0 or 1. In the first L games individuals randomly select cooperation or defection. Then each individual repeat $2^{2L+2}$ games with all their neighbors based on chromosome and game history. For example, if L=3, there should be 64 genes and 256 iterated games. Every node adds its payoff together in each game. After all the games each node divides its total payoffs by its degree to get the fitness. Every node select two nodes of its neighbor as parents (include itself) who have highest fitness. After crossover and mutation (Fig.1), parent chromosomes evolve to two

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children chromosomes. Then one of them is selected as the node's chromosome and the next generation begins. Therefore, successful individuals have more probability to maintain their strategies to offspring.

The process can be described below:

①initialize a BA scale-free network;

②randomly initialize every node's chromosome and first L games;

③each node game with its neighbors for $2^{2L+2}$ times;

④each node select two node among its neighbors (include itself) as parent by node's fitness.

⑤each node evolve to its' children chromosome by crossover and mutation;

⑥repeat 3-5 for 1000 generations;

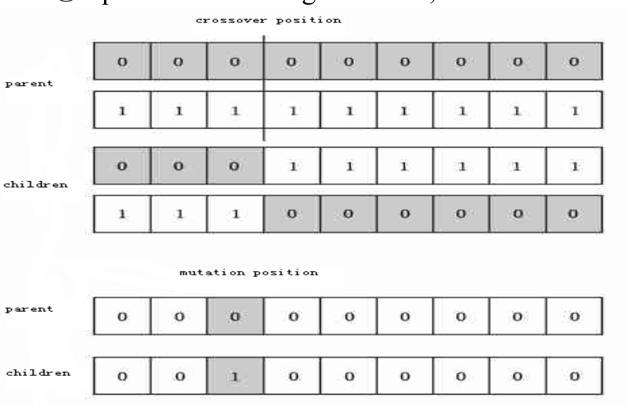


Fig.1 Gene recombination and mutation sketch map

# 3 SIMULATION AND DISCUSSION

Simulation parameters are as follows: the network has 3000 nodes, and average node degree is 6. The values of PDG pay matrix are R=1, T=bR, S=0, P=0.1. The parameter b=T/R represents the advantage of defectors over cooperators. We constrain 1<b<3, so we can inspect how the individual's game strategy change even when defection profits are high. In simulation, the probability of crossover is 0.7, and probability of mutation is 0.001 for each gene. Every individual in every generation repeat $2^{2L+2}$ games with its neighbors. Every statistic value is based on 100 samples.

## 3.1 The Effect of Memory Length to Cooperation in PDG

Cooperation frequency is defined as the proportion of cooperation strategies to all strategies adopted in games by all the individuals.

From Fig.2, we can see that with the increase of memory length, generations evolve to stable level do not decrease, but a certain increase. This is because that when the memory increase, chromosome's length also increases, it means more different history status. Then more generations are needed for individuals to evolve. We can also see that with the increase of memory length, cooperation frequency does not increase, but a certain decrease [11]. This is because that when memory increases, a few betray strategies that got high profits could be remembered, the system cooperation frequency decreased. So we can make conclusion that increase memory in this way can not promote cooperation; On the contrary, individuals with more memory are tricky to get more profits by defection, similar to defection behavior of individuals in society and biologic world.

## 3.2 Emergence of Characteristic Genes in PDG

After 1000 generations, with different memory length and b, we get statistical average values for all genes. Then we get Fig.3. We find that some specific genes tend to specific values.

We can find some general rules from Fig.3. 1. Genes with memory history of all 0 or all 1 have a high probability to cooperate next time. That is to say nodes cooperate with each other will cooperate next time, and nodes defect with each other all the memory history will change to cooperate next time because they have not get any profit. The examples are the genes locating at first (No.0) and last (No.3, m=1, No.15, m=2, No.63, m=3 etc.). 2. "Exploit honest people" and "anti-exploit". The examples are when m=3 gene No.21(010101, its value tends to 0, "exploit honest people") and No.42(101010, its value tend to 0, "anti-exploit"), when m=4 gene No.85(01010101, its value tends to 0) and No.170(10101010, its value tends to 0). Nodes tend to defect to neighbors who cooperate all the time, but the cooperated nodes will change to defect if they find their neighbors always cheat them. These genes can punish defection and promote cooperation finally. 3. Some genes evolve characteristics of oscillation, especially when r is high. The examples are when m=3 gene No.25(011001, its value tend to 1), No.38(100110, its value tend to 0), when m=4 gene No.102 (0110011, its value tend to 0), No.153(10011001, its value tend to 1), and so on. These genes make nodes get more profits.

## 3.3 Frequently Used Genes Distribution in PDG

We focused on frequently used genes distribution when memory length is 3. With different b, the individuals evolved 1100 generation. We counted all the genes that used by nodes of the last 100 generations and got Fig.4.

We can see from the figure that only very few genes are greatly used by nodes. When b=1.5, most nodes take cooperation as their strategy, No.63 genes account for more than 90%. When b=2.5, No.25, No.38 genes each account for almost 50%, and No.63 genes account for small proportion.

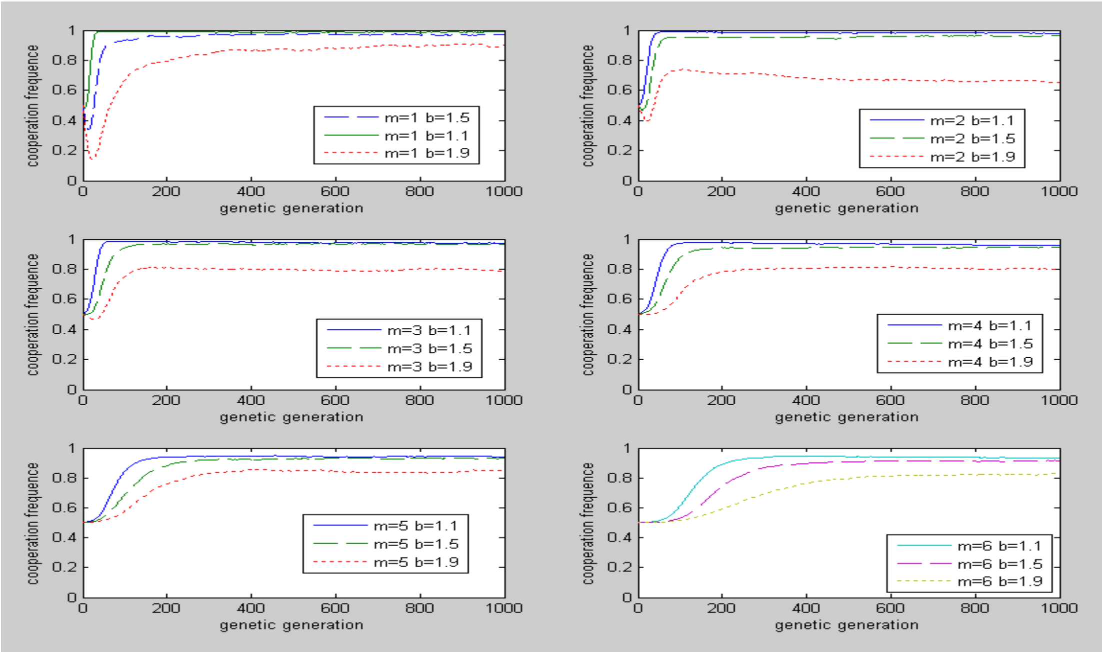


Fig. 2  Cooperation frequency with different memory length m and defection profits b

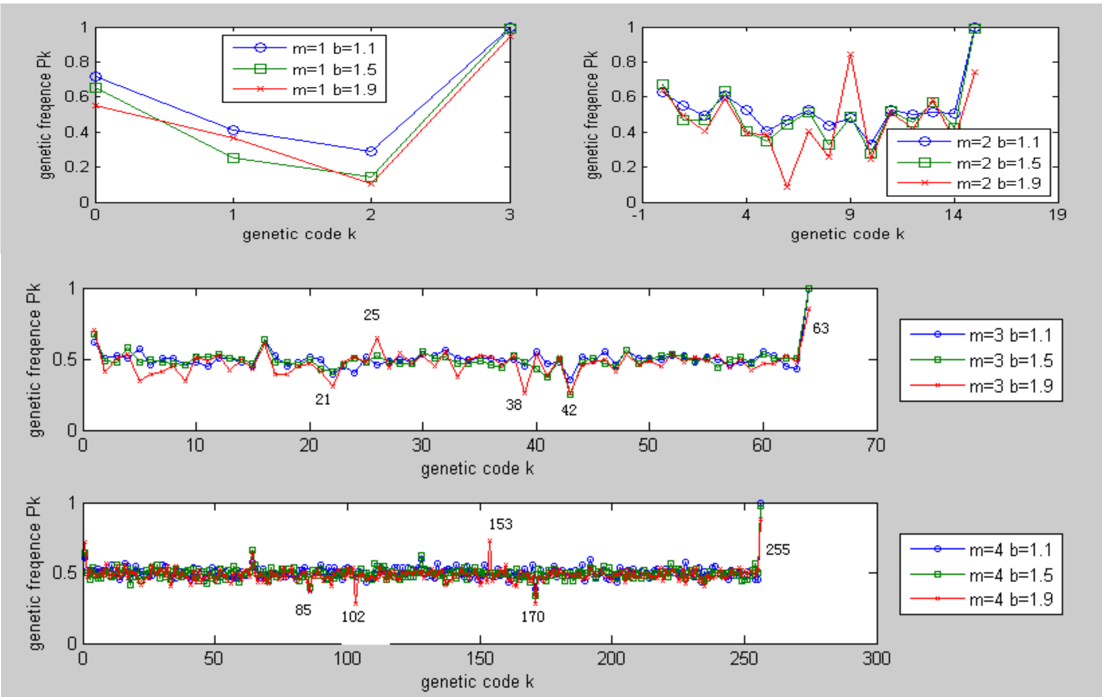


Fig. 3  Characteristic genes in PDG, m means memory length, b means defection profits

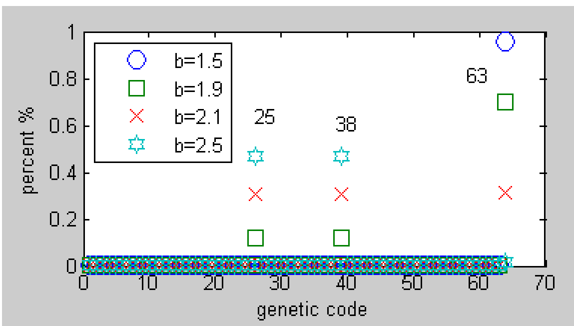


Fig.4  Frequently used genes distribution with different b when individuals reach a stable cooperation level.

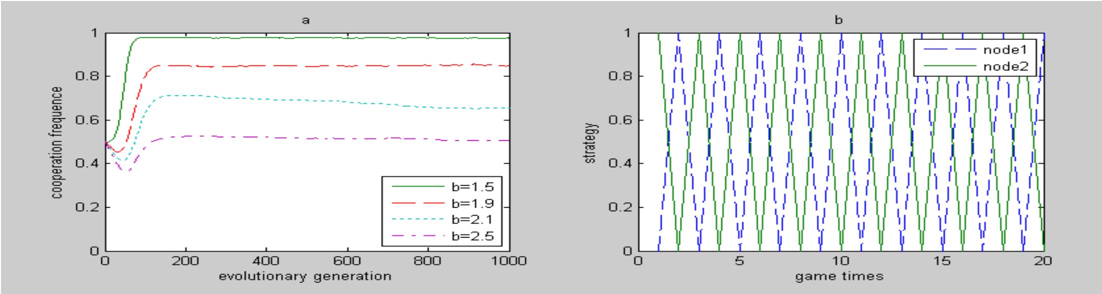


Fig.5 (a) When memory length is3, system cooperation level with high defection profits b.
(b) At 1000 generation, when b=2.5, randomly selected two neighbor-nodes' strategy in the first 20 games

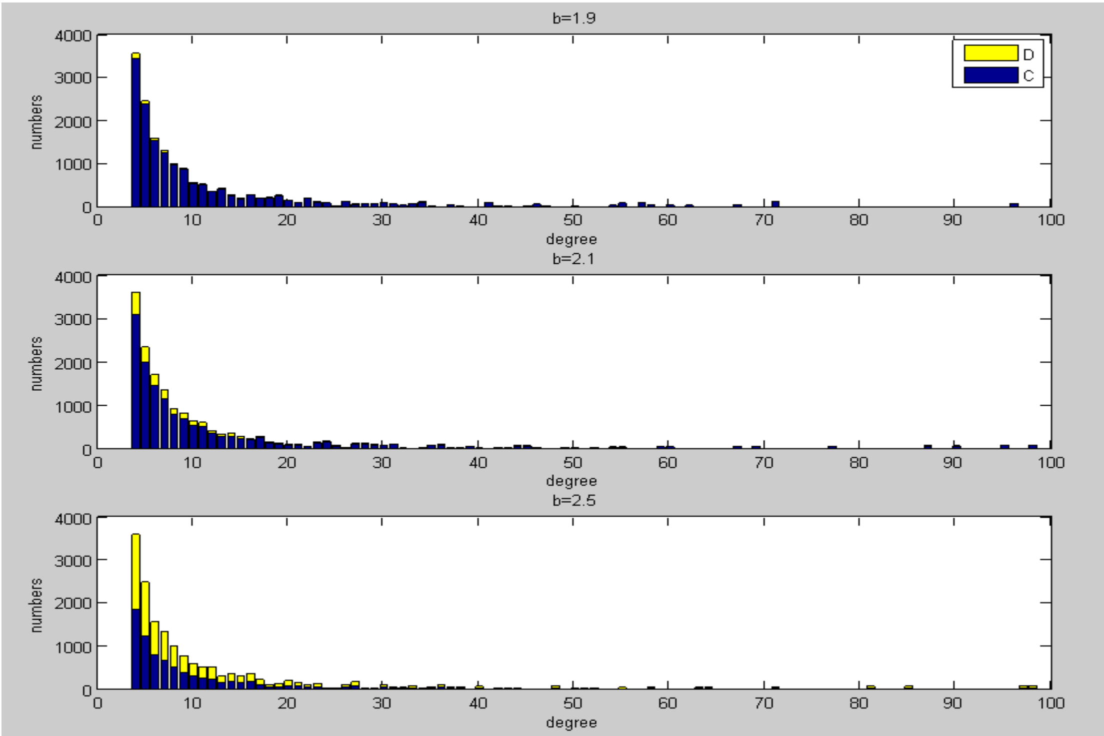


Fig.6 Degree distribution of cooperation-defection strategies

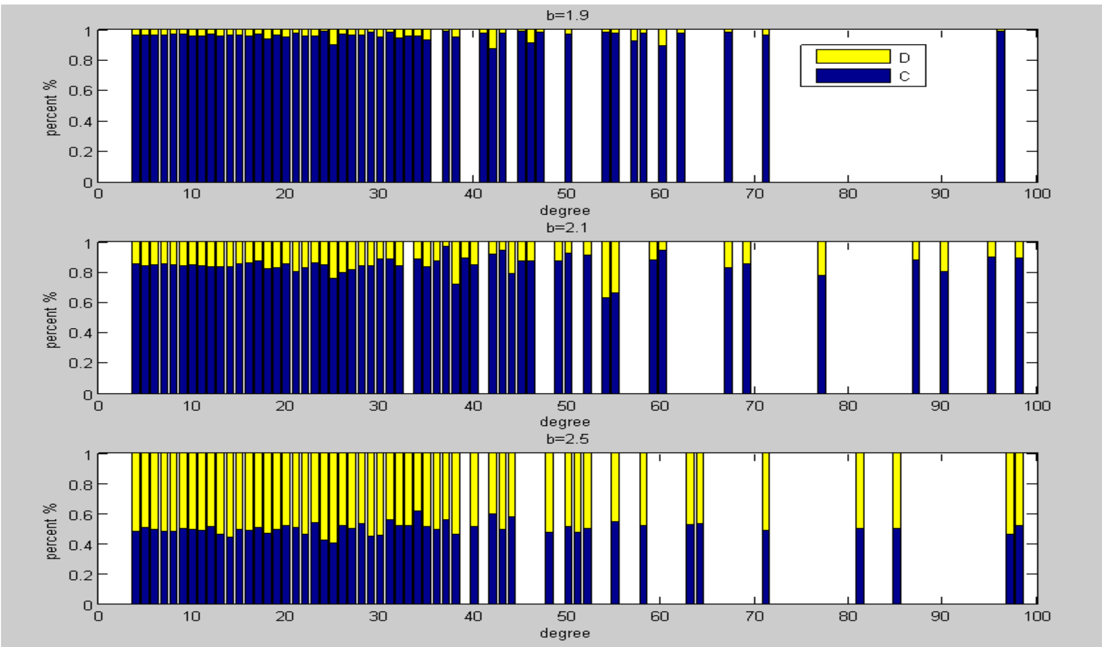


Fig.7 Percent style of degree-distribution of cooperation-defection strategies

It is obvious that when b increases, defector can get more profits from cooperator. No.25 (011001) and No.38 (100110) genes emergence in pair, and the nodes game with each other can get max profit, so these two genes gradually increase their proportion. When b>2, most nodes are in oscillation (01010101… Fig.5b). We can also explain that even when b grows very high, the system cooperation level can be stabilized around 50% (Fig.5a).

### 3.4 Degree-distribution of Cooperation-defection Strategies in PDG

In past researches, cooperation strategy occupied high degree nodes generally. In order to know the relationship between cooperation strategy and nodes' degree, we investigate the degree-distribution of cooperation strategy with memory length=3 and different defection profits. The system evolves 1100 generations. For the last 100 generations we count and average cooperation strategies and defection strategies on different node-degrees. Then we get Fig.6.

In order to get a more clearly degree-distribution of strategies, we get percentages of cooperation-defection strategies on each degree. (Fig.7)

From the figure we can see clearly that when b increases, defection strategies increase. But defection strategies emerge on different degree nodes equably. The reason maybe that every node takes different strategies to different neighbor, and the evolved characteristic genes strongly protect cooperation behavior from distinguish.

## 4 ONCLUTIONS

We have taken genetic algorithm to investigate evolutionary games on BA networks. Different to some researches before, we found that in this model, increasing memory can not increase the system cooperation level, nor can it reduce the system evolved generations to a stable cooperation level. This is because that when memory increased, the high payoff get by defection remembered to offspring by chromosome, and the characteristic genes need more generations to evolved. However, whether how high defect profit is, the system cooperation level is upon 50%. Statistical results show that after some generations, to some particular game history, some genes tend to particular value (0 or 1). Most of these genes can promote cooperation; others help nodes get high payoff by oscillating strategy. When system gets to a stable cooperation level, only few genes are greatly used. When defect payoff is low, most nodes take cooperation genes. While when defection payoff is high, neighbor nodes take defection-cooperation oscillating genes. In addition, we found that different from classic heterogeneous network, defection not only emerged on low degree or high degree nodes, but on most different degree nodes equably. These findings give new perspectives to the illustration of cooperation behavior in biological group and society.

Genetic algorithm is a kind of distributed algorithm that inspired from biological evolution, while evolutionary games are taken to study macroscopic behaviors such as cooperation and self-organization emerged in population made up of independent, selfish individuals. By combined genetic algorithm and evolutionary games together, Independent individuals take different strategies to different neighbors. This is more in line with the actual situation of individual groups such as biological groups and social groups etc. Our next research will focus on the co-evolution of network structure and game with the effects of this kind of genes.

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