Simulating competition-cooperation choice in a market using agents

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Abstract

The objective of this research is to simulate the competition-cooperation choices in the economic market. In this project, we use the agent-based simulation to imitate the companies' behavior, and we use the hawk-and-dove game to describe the game payoff. Four models based on hawk-and-dove game are built for testing the robustness of strategies. Moreover, each model represents different scenarios in real markets, so these models also aim to evaluate the specific choices against different competitors.

In the experiment, we use different measure aaproaches to assess the performance of the strategies, such as win rate, and criteria table proposed in this project. The result illustrates that well-known strategies such as tit-for-tat, AllC show good performance, but the group strategies are not effective in hawk-and-dove model.

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1 Introduction

1.1 Background

Since the science and technologies boosted the economic globalization from the last century[11], the scale of cross-border trade of commodities and services have increasingly expanded[18]. In order to maximize profits, many of the international enterprises follow the trend of globalization, choosing to work together in a cooperate way. For example, Ford company allocate the production of 'Lyman' cars to different companies: design in Germany, processing gearing systems in Korea, pump in USA, and engine in Australia[18]. However, some businesses unfortunately failed in the fierce competition: in 1985, Carnation company was bought out by Nest company[8], Mannesmann was acquired by Vodaphone in 1999, etc[18]. These cases indicate that while the economic globalization provides more opportunities for cooperation, it also eliminates those who cannot manage to handle the competition risks. Therefore, in order to survive in the crisis, lots of companies begin to consider about the cooperation-competition strategies.

Numerous economic theories have been established in recent centuries as the result of burgeoning economics. These theories provide effective business models for solving practical problems, such as Nash Equilibrium, prisoner's dilemma, etc[13]. The hawk-and-dove model is a classical prototype based on the game theory[20] to analyze the cooperation-competition behaviors among a certain group.

1.2 Introduction

This section introduces the basic background knowledge required to understand the whole project. **A. Game Theory**

The non-cooperative game theory proposed by John Nash in 1950 is an ideal technique for studying decision-making problems in the economic field [16]. It provides general mathematical models such as prisoner's dilemma , hawk and dove to analyze the results of mutual decision makings [17].

Generally, a simple game consists of three components: players, strategies(choices), and payoff matrix[21].A basic game usually happens between two players, and each of them adopts strategies independently. After a game, an outcome is given of according to the preset payoff matrix, and the result is that each player will get profits or losses. The payoff matrix gives the information about the relationship between players' choices and their payoffs. Importantly, the game outcome depends on the choices of both the participant and its opponent. A single player's choice can not entirely affect the game result. Moreover, in a non-cooperative game, two players are assumed to be completely self-enforcing, which means they are not allowed to form alliance for higher profits. An example payoff matrix is demonstrated below. A and B represents the strategies here.

	Player 2 chooses A	**Player 2 chooses B**
Player 1 chooses A	v_1, v_2	v_3, v_4
Player 1 chooses B	v_5, v_6	v_7, v_8

Figure 1: Game theory sample table

B. Nash Equilibrium

Nash equilibrium is a well-known concept in game theory. The basic definition of Nash equilibrium is that : Assume that one participant is playing a game with its opponent, two players have already made their choices, and the opponent' choice is unchanged. If the participant can not increase the expected payoff through changing its own strategy, then the Nash equilibrium is reached[16]. This theory is widely used to describe the equilibrium state in a contest, especially in business field.

C. Hawk-and-dove Game

Hawk-and-dove game is a classical model of non-cooperative game theory. The concept was first proposed by John Maynard Smith and George Price in "The logic of animal conflicts" [23]. The players in the game can either choose to be a hawk, or a dove. In this paper, they are regarded as strategy H and strategy D. When the player shows aggression (hawk), it competes with its opponent and fights for the resources. When the player shows mildness (dove), it intends to cooperate with the opponent and share the resource. [21]. Certainly, the final result of the game is not merely decided by one single player's choice, it depends on the combination of two players' strategies.

The outcome of a hawk-and-dove game can be described with a payoff matrix (See Figure 2).

	Meets Hawk	Meets Dove
If Hawk	X, X	W, L
If Dove	L, W	T, T

Figure 2: General Hawk-Dove Game

Usually, $W > T > L > X$ in a general HDG. In this project, we use a more specific model defined by John Maynard Smith [23]:

There are three situations classified by players' choices:[19]

1. Hawk meets Hawk: each one has 50% chance to defect the other one and causes damage C. So, the final result payoff is $V/2 - C/2$ for each.

2. Hawk meets Dove: Hawk plunders all resources V and Dove obtains nothing (0).

3. Dove meets Dove: Players share resources equally and gain $V/2$.

	Meets Hawk	Meets Dove
If Hawk	$\frac{V}{2}-\frac{C}{2}, \frac{V}{2}-\frac{C}{2}$	$V, 0$
If Dove	$0, V$	$\frac{V}{2}, \frac{V}{2}$

Where the V represents the value of resource, and the C represents the damage cost.

Figure 3: Hawk-Dove Game

1.3 Motivation

Hawk-Dove game describes the contest between two players with roles of the competitor and the cooperator for sharable resources [22]. The hawk-and-dove relationship is similar to enterprise s' activity in the market. It is an applicable tool for evaluating cooperation-competition choices in a market. Therefore, it is worth doing research on the simulation of cooperation-competition choices with hawk-and-dove model.

1.4 Aims and Objectives

The main objective of this project is to evaluate the competition-cooperation choice in a market. The system applies various winning strategies and analyzes their performance in several different hawk-and-dove model. The purpose is to identify well-performed strategies, and then test their performance, robustness in different models. In addition, each model represents specific scenarios in real market, and this issue will be discussed in the following sections

Key objectives:

1. Develop a simulation program using agents and spatial game structure.
2. Develop symmetric/asymmetric evolutionary hawk-and-dove model, symmetric/asymmetric iterated hawk-and-dove model.
3. Select potential strategies, carry out experiments to identify well-performed strategies.

4. Evaluate strategies performance and robustness in different models.
5. Elicit the practical meaning of the project in economic areas.

2 Related Work

2.1 Evolutionary and iterated hawk-and-dove game models

Carlsson and Johansson make a specific review on different categories of hawk-and-dove game. They list and describe several basic models of the game theory, such as prisoner's dilemma (PD), chicken game (CG), hawk-and-dove (HD), etc. They also analyze the similarities and differences among these models through delving the payoff matrix. According to Nash equilibrium [1],defecting is a better choice than cooperating in the prisoner's dilemma game, because the payoff matrix shows no matter what action the opponent takes, defect can always maximize the benefits (or minimize the losses).

Prisoner's dilemma		
Player1/Player2	Cooperate	Defect
Cooperate	R, R	S, T
Defect	T, S	P, P

Figure 4: Prisoner's Dilemma

The figure above shows the payoff matrix of a prisoner's dilemma game, where: [3]
$T(Temptation) > R(Reward) > P(Punishment) > S(Suck), and\ R > 1/2(T + S)$
(1) Opponent: Cooperate; Player:$P(Defect) > P(Cooperate)$
(2) Opponent: Defect; Player: $P(Cooperate) > P(Defect)$

Prisoner's dilemma		
Player/Opponent	Cooperate	Defect
Cooperate	$R = 5,$ $R = 5$	$S = 10,$ $T = 0$
Defect	$T = 0,$ $S = 10$	$P = 3,$ $P = 3$

Prisoner's dilemma		
Player/Opponent	Cooperate	Defect
Cooperate	$R = 5,$ $R = 5$	$S = 10,$ $T = 0$
Defect	$T = 0,$ $S = 10$	$P = 3,$ $P = 3$

Figure 5: An example of Nash Equilibrium in Prisoner's Dilemma

Though there is no pure strategy in hawk-and-dove game to reach the Nash equilibrium [3], the mixed equilibrium strategy based on probability can be applied to attain the stability in a hawk-and-dove game. This will be discussed in detail in the section Methodology. Meanwhile, the author compares the main difference between the iterated HDG and the evolutionary HDG (which is also known as repeated HDG): iterated games record its previous move while repeated games only focus on the current move.

In this paper, as the cooperation-competition model is more relevant to our study, we choose to use hawk-and-dove game to conduct this research. In addition, in order to test the strategies' robustness in various scenes, evolutionary HDG is also included in our experiment.

2.2 Winning strategies in iterated games

Li mainly focuses on the winning strategies for evolutionary PD games and iterated PD games. He selects multifarious strategies including some classical approaches like Tit-for-Tat [10], as well as some group strategies. The author also develops an approach to evaluate the performance of strategies, which primarily measures two dimensions of a strategy: winning rate, and average profits. These two parameters analyze the strategy's competitive ability and occupation proportion in the confined space. Considering that the hawk-and-dove game is similar to the PD game, this paper refers to Li's evaluation approach as well as some well-established strategies he mentioned.

2.3 Asymmetric Hawk-and-Dove game

In Song and Huang' paper, they adopt the asymmetric hawk-and-dove game model to assess the cooperation-competition actions in strategic alliances. In a traditional game, the game model assumes that the power of two players are totally the same. This is to say, when two players take the same action, they always get equal pays. Therefore, the traditional payoff matrix is completely symmetric. However, in strategic alliances relationship, the conflict result also depends on the size of an alliance. Due to some factors such as negotiation ability, team capacity, experiences, etc. stronger individual loses less in a conflict and wins more rewards in the cooperation; weaker individual faces larger risks, and has worse stability. Therefore, the author explains the asymmetric hawk-and-dove (AHD) model is a more accurate model to analyze the contest between two players with large strength gap. For this paper, despite the classical HDG, AHD model is also applied to describe the specific pattern of the market.

3 Overview

This section mainly introduces the composition of the whole project. In addition, different scenarios are defined and explained as well. Our method consists of four modules:

1. Symmetric Evolutionary HDG.
2. Symmetric Iterated HDG.
3. Asymmetric Evolutionary HDG.
4. Asymmetric Iterated HDG.

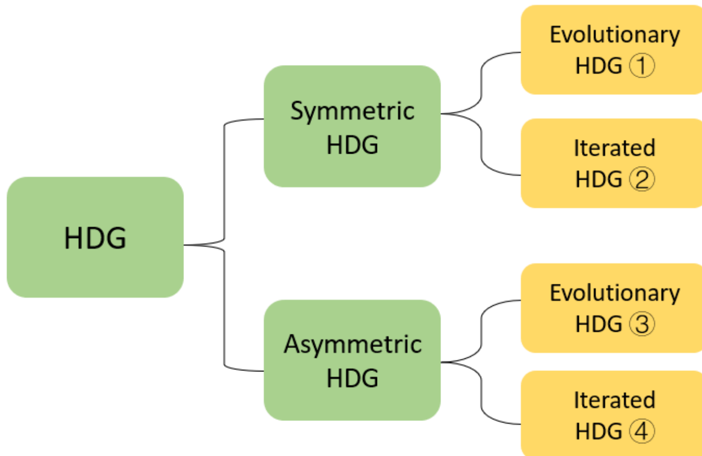

Figure 6: Modules

The symmetric game interprets the contests among companies with similar size. The SHDG aims to analyze the contests of which the participant has equal power with its opponent. In contrast, the asymmetric game describes a more complicated system in which individuals are set with different sizes. In a real economic market, the wealth power of many companies varies widely, and larger companies always gain more bonus, avoiding more losses. Therefore, the asymmetric game is to evaluate the contests that partly dominated by the individual's power.

As mentioned in the Related Work, the difference between evolutionary and iterated game is that the individuals in iterated games record previous move of opponents. Therefore, the evolutionary game is more like the process of natural selection[darwin], which means the generation change and game results are only affected by the laws of natue (payoff matrix represents the laws of nature in this project). We introduce the evolutionary game to test the rule of competition-cooperation when there is no any human intervention. On the other hand, since the iterated game is able to remember previous decisions of opponents, individuals in the iterated game can design elabo-

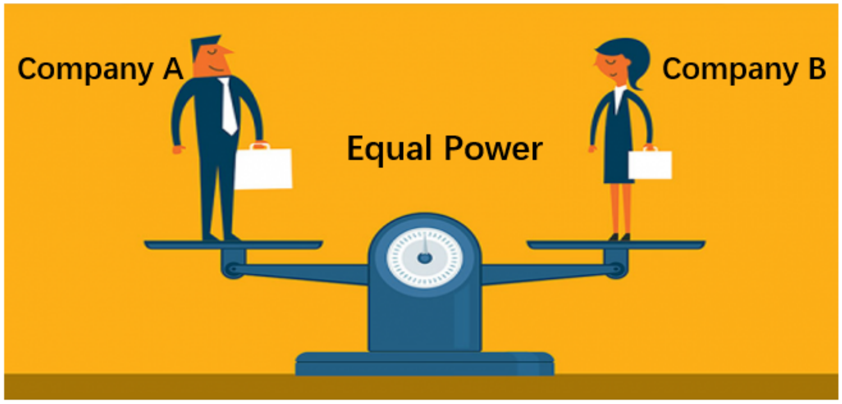

Figure 7: Symmetric Contest

Figure 8: Asymmetric Contest

rate strategies with careful consideration. For example, some strategies are built to explore and exploit the opponent such as Tit-for-Tat (TFT is introduced in following sections). Therefore, iterated games is applied to analyze performance of intelligent, well-designed strategies.

4 Design

4.1 System Design

The design of the system is divided into four steps. Firstly, the system randomly assigns strategies to 200*200 agents. Secondly, each agent starts to carry out 1v1 hawk-and-dove game. During this step, the program records average profits or losses for every agent. Thirdly, each agent evolves according to the payoff recording. Better strategies have higher possibilities to be learned by generations. Finally, when the evolution reaches a certain point, the ratio of strategies in the system becomes stable. Then the program records the stable ratio, and repeatedly carries out experiments to increase the accuracy of the results.

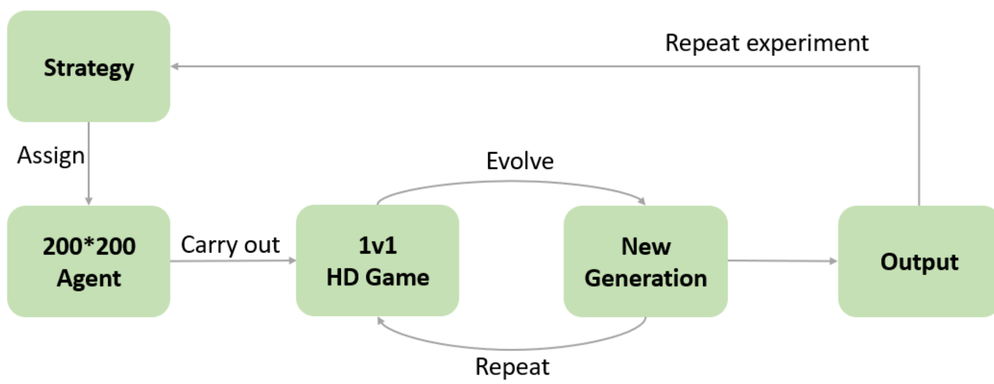

Figure 9: Evolutionary Hawk-and-dove Game

The whole system is composed of four separate sub-systems. The multiple sub-systems are designed for simulating multifarious environments as well as analyzing the robustness of the testing strategies:

1. Evolutionary Hawk-Dove Game
2. Iterated Hawk-Dove Game
3. Asymmetric Evolutionary Hawk-Dove Game
4. Asymmetric Iterated Hawk-Dove Game

In an evolutionary game, an agent plays the 1v1 hawk-and-dove game with each of its neighbor for only once of each generation. By contrast, in an iterated game, 1v1

HD game is played for multiple times iteratedly before each evolution. The rationale is discussed in the following sections.

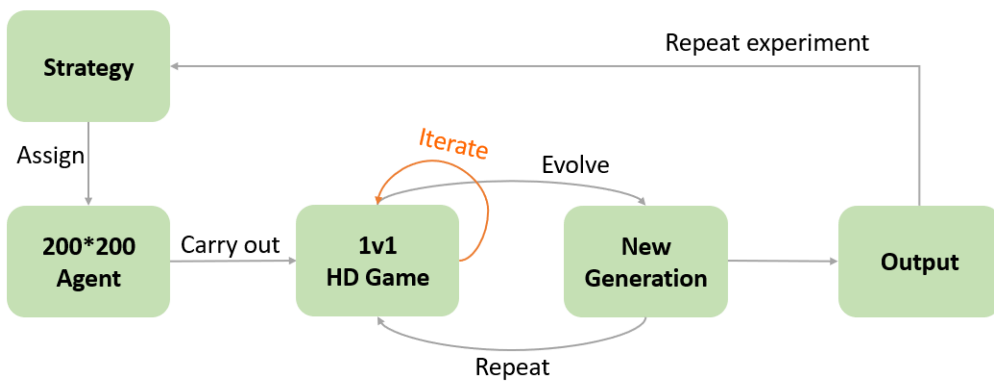

Figure 10: Iterated Hawk-and-dove Game

5 Methodology

5.1 Agent-based Simulation

Agent-based modeling (ABM) is a methodology applied to build real world models. In a fundamental agent-based model, each individual is composed of small units, such as cells, people. These individual units in the system repeatedly interact with each other and have effects on one another. One feature of the ABM is that it enables explicit correspondence and communication among the units [5]. Therefore, the system is widely-used to represent the interaction and the behaviors of individuals. Another advantage of ABM is that it can transform the complicated chaos into a simplified environment, which improves macroscopical interpretation of the whole system and also lower the difficulty in system implementation [6].

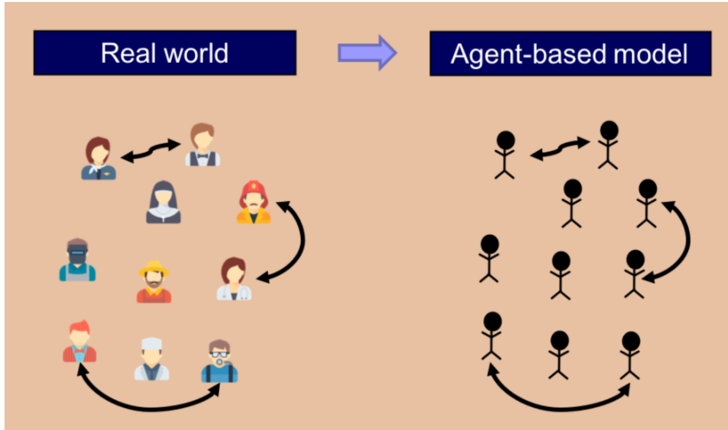

Figure 11: Agent-Based Modelling

5.2 Evolutionary Hawk-and-dove Game

A. Evolutionary Game

In the nature, species with weak genes are gradually eliminated and replaced, while species with good heritable phenotypes continue to reproduce. This optimizing process is known as the natural selection, and the adaptive ability of a specie is described as fitness. The evolutionary game is based on Darwin's biological evolutionism and natural selection theory which constantly evolving populations through eliminating the inferior and retaining the superior [25].

The basic HDG only involves two players, but the evolutionary game should include a group of individuals playing pairwise game with one another. The strategies represent heritable phenotypes, and payoffs reflect the fitness. As the generations evolve, the individuals with lower fitness should learn from other players, and the populations with higher payoffs should spread their strategy to those learners [25].

Assume that each individual has initial fitness W_0:[21]
p =frequency of strategy H in the population,
$W(H)$ = fitness of strategy H, $W(D)$ = fitness of strategy D,

$E(H, D)$ = payoff to individual with strategy H against an opponent adopting D.

$E(S, H)$ = payoff to individual with strategy D against an opponent adopting H.

Then in a contest, the fitness of strategy H and strategy D can be described as:

$$W(H) = W_0 + pE(H, H) + (1 - p)E(H, D), \tag{1}$$

$$W(D) = W_0 + pE(D, H) + (1 - p)E(D, D). \tag{2}$$

B. Evolutionarily Stable Strategy

Evolutionarily stable strategy (ESS) is an equilibrium refinement of the Nash equilibrium. ESS is a strategy that if all the members in a certain group adopt it , then no mutant strategy can invade the population under the influence of natural selection. Therefore, if strategy I is identified as an ESS, it means almost all individuals adopt I, and the payoff of those strategies is greater than the fitness of any other possible strategy. Conversely, if there exisits a mutant strategy that can invade the population and reach a higher fitness than I, then I is not a evolutionarily stable strategy[21].

Let I be the ESS among a certain population, then we can reach the conclusion that :[21]

$$W(I) = W_0 + pE(I, I) + (1 - p)E(I, J), \tag{3}$$

$$W(J) = W_0 + pE(J, I) + (1 - p)E(J, J). \tag{4}$$

Since I is stable, $W(I) > W(J)$, $I \neq J$, then we have:

$$\begin{aligned} &either \qquad && E(I, I) > E(J, I), \\ &or && E(I, I) = E(J, I) \ and \ E(J, I) > E(J, J). \end{aligned}$$

In an evolutionary HDG, we can see clearly from the payoff matrix: $E(D, D) <$

$E(H, D)$. So, *Dove* is not a stable strategy, it can be invaded by a mutant strategy *Hawk*. On the other hand, *Hawk* can be an ESS if $(V - C) > 0, or\ V > C$. Namely, this means the resource V is valuable enough for a hawk to risk injury to obtain. But if $V < C$, *Hawk* is not a stable strategy either. Under this circumstance, there is no pure ESS for an evolutionary hawk-and-dove game.

	Meets Hawk	Meets Dove
If Hawk	$\frac{V}{2} - \frac{C}{2}, \frac{V}{2} - \frac{C}{2}$	$V, 0$
If Dove	$0, V$	$\frac{V}{2}, \frac{V}{2}$

Figure 12: Hawk-Dove Game

The evolutionary game is not a one-time game. On the contrary, it is constantly changing, and the members in the population are constantly evolving into new generations. More specifically, the ever-changing populations means each individual in the group can adopt a new strategy in the next generation. Therefore, the mixed strategy is proposed by Smiths to interpret a stable system. A mixed strategy represents the mixture of several kinds of strategies, for example, in hawk-and-dove game, the mixed strategy I can sometimes adopt H and sometimes D. Strategy I can be defined as play H with probability P, and play D with probability (1 - P). Under this circumstance, even though there is no pure ESS for EHDG of a single generation, a mixed strategy can lead the environment to reach a equilibrium in the long run.

If I is an ESS, the expected payoffs of the pure strategies A, B, C... composing I should be equal. Otherwise, strategies with higher fitness will be adopted more often, and the stable equilibrium can not be not reached. For example, if $E(A, I) > E(B, I)$, then strategy A will be adopted by more members in the next generation due to its higher payoff. Bishop & Cannings have proved that if I is a mixed ESS, and I contains pure strategies: A, B, C..., where A, B, C... are with non-zero probability. Then, we have:

$$E(A, I) = E(B, I) = E(C, I)... = E(I, I). \quad (5)$$

Therefore, to find the mixed strategy in a hawk-and-dove game, we need to solve the equation:

$$E(H, I) = E(D, I), \quad (6)$$

$$W(H) = W(D) \quad (7)$$

Therefore, we have

$$p\ E(H, H)\ +\ (1-p)\ E(H, D) = p\ E(D, H)\ +\ (1-p)\ E(D, D), \quad (8)$$

$$\frac{1}{2}(V - C)\ p\ +\ V\ (1-p) = \frac{1}{2}V\ (1-p), \quad (9)$$

Then,

$$p = V/C \quad (10)$$

5.3 Iterated Hawk-and-dove Game

A. Iterated Game

As mentioned in the Related Work, evolutionary game is infinitely repeating without retaining any previous information. The individuals in the evolutionary game only know current payoffs , they can merely evolve themselves through learning a strategy with higher fitness. So the evolution action is more like the natural selection process, no intelligent consideration or reflection. By contrast, an iterated hawk-and-dove game (IHDG) is also infinite happening between two or more players, but players in the IHDG have the option to remember the previous moves of both the opponents and itself[9, 3]. Therefore, players in an iterated game can target to fight against a specific opponent according to its previous moves. For example, the members in IHDG can purposely use counter strategies to defeat its opponent.

More specifically, in evolutionary hawk-and-dove game, there are only two decisions: to be a $Hawk$, or to be a $Dove$. In an iterated game, more choices can be made, such as the circulation of $Dove\ -Hawk\ -Dove$ in the consecutive generations. Moreover, some strategies make decisions according to opponent's previous action. For example, the well-known strategy Tit-for-Tat defines that the player cooperates on the first move, then does whatever your opponent did on the previous move[15]. More tested strategies are introduced in $Section 5.3.D$.

B. Spatial Iterated Game

Since the system requires large population of individuals to interact with each other in a certain environment, a spatial structure is applied to implement the interaction in this project. The prototype of spatial game model is first introduced by Nowak & May in 1992.[14] Th central concept of spatial game is that of the spatial interaction with neighbors. In a spatial game, we assume that each individual is randomly distributed over a confined region. Then the individual needs to interact with each of its neighbors through the chosen strategy. The generation evolution in the game is carrying on through the strategy update: each individual replaces unsuccessful strategies with successful ones which gained from its neighbors[24].

First, we introduce a $L * L$ square Lattice A, where $L * L$ individual cells are evenly distributed. Then, we consider there is a finite number of strategies, denoted by Σ. Each of the cell is occupied by a strategy from the strategy set Σ. These cells are labelled as I, and each of the cell connects to one or more neighbors. The neighbor sets of I is defined as $N(I)$. In a spatial game, each individual only plays game with neighbors, rather than all members in the population. Then, we use $E(i, j)$ to represent the value (payoff) of an individual adopting strategy $i \in \Sigma$ against its opponent adopting strategy $j \in \Sigma$. In spatial evolutionary game, a dynamic process, a strategy is defined as $\sigma_t(I) \in \Sigma$ at t generation. Therefore, the total payoff of I playing with all its neighbors at t generation is:[24]

$$s_t(I) = \sum_{J \in N(I)} E\ (\sigma_t(I),\ \sigma_t(J)) \tag{11}$$

To introduce strategies with memories, each cell I may play with its opponents J with multiple rounds for each generation. The player may make choice according to the last move of its opponent. Therefore, the total payoff at generation t is :

$$s_t(I) = \sum_{r=0}^{rounds} [\sum_{J \in N(I)} E\ (\sigma_t(I),\ \sigma_t(J))] \tag{12}$$

C. Strategy Performance Measurement

Usually, an individual evolves itself by learning a new strategy with higher payoff. In a spatial game, each individual has different numbers of neighbours. In this case, the total payoff is not a proper index to measure the performance of a strategy. We use the average payoff as the measure for the performance of a strategy in the spatial game[9]. It is also the measure for the strategy adoption in the evolution process. We assume the player has n neighbors, then the average payoff:[9]

$$s_a(I) = \frac{1}{n} * \sum_{r=0}^{rounds} [\sum_{J \in N(I)} E\ (\sigma_t(I),\ \sigma_t(J))] \tag{13}$$

For example, a player A has 3 neighbors, and A gains 1 from game with each neighbor. The total payoff to A is 3. The player B has 1 neighbor, and A gains 2 from game with its neighbor. The total payoff to B is 2. $Total\ Payoff_A\ > Total\ Payoff_B$. However, we can see that the average profits for A (1) is lower than B (2).

D. Strategies in Iterated Games

This section introduces some common strategies that are implemented in the experiments in this project. In order to simplify the description, the choice of *Dove* is called *Cooperate*, and the choice of $Hawk$ is called $Defect$ in the following definition[9, 10, 4].

(1). *AllD*: The strategy $Always\ Defect$ always play as a $Hawk$ ($Defect$).

(2). TFT: The strategy $Tit-for-Tat$ starts with *Cooperate*, and then repeats the opponent's moves.

(3). *AllC*: The strategy *Always Cooperate* always play as a *Dove* (*Cooperate*).

(4). *Grim*: The strategy *Grudger* starts with cooperate, once the opponent choose to defect, then the player always chooses to defect.

(5).$TFTT$: The strategy $Tit-for-two-tats$ adopts *cooperate* on the first move, then repeat cooperate if the opponent cooperates, and only chooses to defect when the opponent defects for two consecutive times.

(6).$STFT$: The strategy $Suspicioustit-for-tat$ starts with defect, and then repeats the opponent's moves.

(7).$Pavlov$: The strategy $Pavlov$ cooperates on the first move. Then the move is divided into two types: Success($Dove-Dove$, $Hawk-Dove$)and Defeat ($Dove-Hawk$, $Hawk-Hawk$). When the last move is from SUCCESS, it repeats the previous move, otherwise, it plays the opposite move.

(8). *Rand*: The strategy randomly choose to play cooperate or defect, with the equal probability of $\frac{1}{2}$.

(9). NEG: The first move is random, and then play the opposite of the opponent's last move. Namely, if the opponent play cooperate for the last move, it plays defect in this round; if the opponent play defect for the last move, it plays cooperate in this round.

(10). $TTFT$: The strategy $Two-tits-for-tat$ is similar to $tits-for-tat$, but defects for twice if the opponent chooses to defect for the last move.

(11). FBF: The strategy $Firmbutfair$ starts with a coopearte move, and then cooperates unless receiving a $Dove-Hawk$ payoff.

(12). *Gradual*: The strategy *Gradual* cooperates on the first move, and cooperates if its opponent cooperates. When it encounters the first defection of its opponent, it defects once, and then cooperates for two times. After nth defection it received, the player reacts with n consecutive defection, and then calms down the opponent with two cooperates.

(13). *Adaptive*: The strategy *Adaptive* starts with C, C, C, C, C, C, D, D, D, D, D, and then it makes the decision by recalculating the average score, and take the choice with the best score.

(14). C_TFT: The $Contritetit-for-tat$ is the same as $tit-for-tat$, but with no noise. With the noise, if it receives T due to error, it will cooperate twice to recover mutual cooperation.

(15).G_TFT: The strategy $GenerousTFT$ is the same as $tit - for - tat$, but when the opponent defects, it cooperates with the probability of q.

(16). *Probe*: It starts with D, C, C, and then if the opponent cooperate in the second and third move, it defects. Otherwise, the $PROBE$ plays $tit - for - tat$.

(17). *Group*: The main idea of the group strategy is to unite several players together, and one of them plays as 'master', others play as 'slave'. The master always defect, and the slave always cooperate so that the master get win higher payoffs.

5.4 Asymmetric Hawk-and-dove Game

A. Asymmetric Hawk-and-dove Game

Traditional hawk-and-dove game illustrates the interaction between two players of equal relationship. However, in real business world, large companies always have strong capabilities to exploit profits from weak ones. Moreover, powerful enterprises also know better about how to avoid losses. On the contrary, weak companies are susceptible to the failure in a contest. Therefore, the asymmetric game is a suitable concept to describe this kind of unequal relationship.According to Smiths, the difference between the symmetric game and asymmetric game is that the asymmetric game contains more external factors that can have influence choice of action.

Let k and $(1 - k)$ represent the relative strength of two players, where $0 < k < 1$. For example, if the strength of company A is k, then its opponent B has the strength k. We use an asymmetric factor$u$to define the asymmetric degree of the individuals: [2, 12]

$$u = \frac{k}{1 - k} \tag{14}$$

Then we assume:

(1). The payoff of two players' cooperation is V, and the cost of a conflict is C, where $C \geq V$. (If $C \leq V$, then payoff of a conflict can always be higher than a cooperation, which is contrary to the actual situation.)

(2). If both players choose to adopt *Hawk*, the payoff to the member who has the strength k is $\frac{v-c}{4k}$; the payoff to the member with the strength $(1-k)$ is $\frac{v-c}{4(1-k)}$. The multiplication of $\frac{1}{4}$ in this equation is used to normalize the model into the classical symmetric hawk-and-dove game when $k = 0.5$.

(3). If both players choose to adopt *Dove*, the payoff to the member who has the strength k is kv; the payoff to the member with the strength $(1-k)$ is $(1-k)v$.

(4). If two players adopt different strategies, namely, one player adopts *Hawk*, and the other player adopts *Dove*, the payoff to *Hawk* is v, and the payoff to *Dove* is 0.

The payoff matrix is shown as follows:

Player A/B	Meets Hawk	Meets Dove
If Hawk	$\frac{V-C}{4k}, \frac{V-C}{4(1-k)}$	$V, 0$
If Dove	$0, V$	$kv, (1-k)v$

Figure 13: Asymmetric Hawk-and-dove Game

We also assume that player A choose to be a *Dove* with the probability of x, and *Hawk* with the probability of $(1-x)$. Similarly, player B choose to be a *Dove* with the probability of y, and *Hawk* with the probability of $(1-y)$. Therefore, the expected payoff the individual A and individual B are:

$$E_A(x,\ y) = (1-x)(1-y)\frac{v-c}{4k} + (1-x)yv + x(1-y)*0 + xykv \tag{15}$$

$$E_B(x,\ y) = (1-x)(1-y)\frac{v-c}{4(1-k)} + (1-y)xv + y(1-x)*0 + yx(1-k)v \tag{16}$$

B. Nash Equilibrium in Asymmetric Hawk-and-dove Game

According to the definition of Nash Equilibrium, the goal of player A is to reach the maximum expected payoff. Namely, the player A attempts to find the x that can maximize the $E_A(x,\ y)$. Therefore: [2, 12]

$$\frac{\partial E_A(x,y)}{\partial x} = \frac{(1-y)(c-v)}{4k} - vy + kvy = 0 \tag{17}$$

$$y_0 = \frac{c-v}{c-v+4kv-4k^2v},\ y_0 \in\ [0,1] \tag{18}$$

Similarly, for player B, the y to maximize the $E_B(x,\ y)$:

$$\frac{\partial E_B(x,y)}{\partial y} = \frac{(1-x)(c-v)}{4(1-k)} - vx + (1-k)vx = 0 \tag{19}$$

$$x_0 = \frac{c-v}{c-v+4kv-4k^2v},\ x_0 \in\ [0,1] \tag{20}$$

Therefore, we get the mixed strategy for Nash equilibrium that can maintain the stability of an asymmetric contest. Then we extend the pairwise contest to a certain population which consists of two types of players A, and B. Under this circumstance, x of the members in A adopt *Dove*; $(1-x)$ of the members in A adopt $Hawk$; y of the members in B adopt *Dove*; $(1-y)$ of the members in B adopt $Hawk$, where $x,\ y \in [0,\ 1]$.

6 Experiment

6.1 Experiment Definition

A. Agent-based Simulation

To simulate a real market environment, a 200*200 spatial structure is built to contain 40,000 individuals that each of them has four individually-owned variables:[7]

- strategy (an integer)
- payoff (an integer)

- co-players (the set of agents with whom this agent plays the game)
- color (RGB value)

Strategy and payoff are stored in two separate 200*200 matrixes with one-to-one correspondence. Every individual plays game with its adjacent cells, and these neighbors are co-players in this project. Every strategy has its own color, for example, 'ALLC' is in red, 'ALLD' is in green. The color of the agent depends on what strategy it is using currently.

B. Hawk-and-dove Game

In this project, we use a classical (also the most common) hawk-and-dove payoff matrix for experiments and evaluation. The Value V is set to 2, and the Cost C is set to 4. Therefore, in this specific model, when Hawk meets hawk, each of them get -1 for penalty; when Dove meets Dove, they share resource and gain 1 for each; when Hawk meets Dove, the Hawk sucks all resource and get 2, and the Dove runs away and gain nothing(0).

	Meets Hawk	Meets Dove
If Hawk	-1, − 1	2, 0
If Dove	0, 2	1, 1

Figure 14: HDG payoff matrix for this project

C. Asymmetric Hawk-and-dove Game

For the asymmetric hawk-and-dove Game, we use the same value for Value V and Cost C, where V is also set to 2, and the Cost C is set t 4. In an asymmetric hawk-and-dove Game,the population is divided to two groups of members: one is privileged in the contest, and the other one is relatively vulnerable. In this project, these two groups represent big company and small company. The big companies take advantage over small companies that they always gain more profits, and lose less than small companies. The payoff matrix is:

K=0.8, Player A/B	Meets Hawk	Meets Dove
If Hawk	-0.625, − 2.5	2, 0
If Dove	0, 2	1.6, 0.4

Figure 15: Asymmetric HDG payoff matrix for this project

D. Spatial Structure

In this project, we use a 200*200 square Lattice A occupied by 40000 individual cells. Each of the cell connects to 3, 5, or 8 neighbors, where the cells at the corner only has 3 neighbors; the cells adjacent to the edge of Lattice have 5 neighbors; and the cells neither at the corner nor adjacent to the edge have 8 neighbors. These three situations are shown below in figures. In the spatial game, each individual only plays game with neighbors, which means in a one round model, one player may play 3, 5, or 8 times of game in one generation.

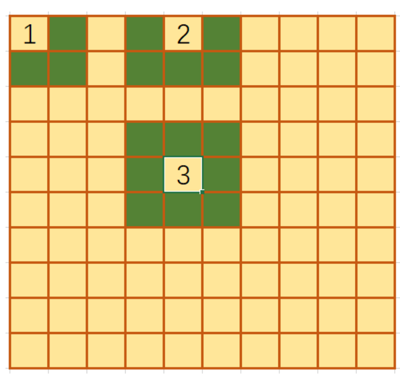

Figure 16: Spatial Structure

6.2 Experiment Design

The experiment can be divided into six separate parts:

I. Symmetric Evolutionary HDG.

The first experiment is a traditional repeated hawk-and-dove game (not a spatial game, the details are discussed in the following parts). From the view of the whole population, this experiment aims to test the ESS in the pure population, as well as to evaluate the proportional relationship of *Hawk* and *Dove*.

II. Symmetric Iterated HDG1 (All).

The second experiment is a spatial iterated hawk-and-dove game. Various strategies have been tested and evaluated in a hawk-dove population. All of the strategies are allocated with equal proportions in the beginning of the game. This experiment attempts to test the performance and the winning rate of different strategies.

III. Symmetric Iterated HDG2 (Compare).

This experiment is also a . Only two strategies are tested together in each sub-trial, with the proportions of 50%:50%, 30%:70%, 70%:30%, 10%:90%, and 90%:10%. This experiment is to test if one strategy has an advantage over the other one.

IV. Asymmetric Evolutionary HDG. This experiment is same as the first experiment, but with an asymmetric payoff matrix. This game is to test the Nash equilibrium mixed strategy in an asymmetric game. As mentioned before, the asymmetric game describes the contest between individuals with large strength gap. Therefore, another goal of this experiment is to evaluate the proportional relationship of *Hawk* and *Dove* within a more complicated population.

V. Asymmetric Iterated HDG1 (All). The fifth experiment is similar to Symmetric Iterated HDG1 (All). The only difference is the payoff matrix. This experiment intends to explore the performance of different strategies in the mixed population. In addition, another obejective is to find out the preference of different group of individuals(big company and small company) for each strategy.

VI. Asymmetric Iterated HDG2 (Compare). This experiment also uses subtrials to test if one strategy has an advantage over the other one. Moreover, it also records the preference of different group of individuals for each strategy.

6.3 Experiment Implementation

I. Symmetric Evolutionary HDG.

As mentioned in Methodology, in an evolutionary game, individuals do not remember the previous actions. Therefore, there are only two strategies in an evolutionary game: Always Cooperate, Always Defect. The game process is described as follows:

1. At the beginning of the game, the system randomly allocates *AllC* and *AllD* to 10000 players. The game is carried out for five times with different initial proportion of the $Hawks$ and the *Doves*: 10:90, 30:70, 50:50. 70:30, 90:10.
2. Then each individual plays the game with its neighbors, using the allocated strategy. In the spatial structure, every cell needs to play game with 3,or 5, or 8 neighbors according to their positions in the Lattice. Then the individual gain the payoff of itself (original payoff) in the current generation.
3. After the game, each player needs to decide which strategy to adopt in the next generation, and this process is called evolution. The player first calculates the potential payoff for adopting a new strategy. Then the player compares the payoffs of the original strategy and the new strategy. Finally, it decides to change to the new strategy, or maintain the original choice.
4. Each individual evolves immediately after the comparison of the payoffs.
5. The system repeat the experiment for — times(generations).

In this project, the spatial game is not applied in evolutionary games, because the aim is to find and test the ESS. In a traditional evolutionary game, each individual evolves immediately after the comparison step. In a spatial game, all players evolve at the same time after all players have done the comparison.

I also did the experiment of spatial evolutionary games, the results are very different from the traditional games. But due to the time limits, the spatial evolutionary game is not evaluated.

II. Symmetric Iterated HDG1 (All).

In this experiment, all of the eighteen strategies introduced in the Methodology are implemented. The game process is described as follows:

1. At the beginning of the game, the system randomly and evenly distributed all strategies to 40000 players. Each strategy turns up with a equal probability, which is 5.56% in this project.
2. Then each individual plays the game with each of its neighbor iteratedly for 50 rounds, using the allocated strategy. In the spatial structure, every cell needs to play game with 3,or 5, or 8 neighbors according to their positions in the Lattice. Then the system records the average payoff of the players.
3. After all players have finished the iterated contests, each player learns the best strategy from its neighbors. This means, the player compares the average payoffs of each of its neighbor, including itself, and adopts the strategy that with the highest average payoff.
4. The evolution step is carried out after all individuals in the Lattice have calculated and compared the average payoffs.
5. The system repeat the experiment for — times(generations).

III. Symmetric Iterated HDG2 (Compare).

In this experiment, all of the eighteen strategies introduced in the Methodology are implemented, but only two strategies are tested in each sub-trial. The game process is described as follows:

1. At the beginning of the game, the system randomly allocated two strategies to 40000 players. The game is carried out for five times with different initial proportion of the strategy 1 and the strategy2: 10:90, 30:70, 50:50. 70:30, 90:10.
2. Then each individual plays the game with each of its neighbor iteratedly for 50 rounds, using the allocated strategy. In the spatial structure, every cell needs to play game with 3,or 5, or 8 neighbors according to their positions in the Lattice. Then the system records the average payoff of the players.
3. After all players have finished the iterated contests, each player learns the best strategy from its neighbors. This means, the player compares the average payoffs of each of its neighbor, including itself, and adopts the strategy that with the highest average payoff.
4. The evolution step is carried out after all individuals in the Lattice have calculated and compared the average payoffs.
5. The system repeat the experiment for — times(generations).

IV. Asymmetric Evolutionary HDG. This experiment is similar to the Symmetric Evolutionary HDG. The only difference is that the population is divided into two groups, and one group represents big companies, the other group represents small companies. In addition, the payoff matrix is also different. The game process is described as follows:

1. At the beginning of the game, the system randomly chooses 30% individuals to represent the big companies, the remaining 70% represents the small companies. Then the system randomly allocates *AllC* and *AllD* to 10000 players. The game is carried out for five times with different initial proportion of the *Hawks* and the *Doves*: 10:90, 30:70, 50:50. 70:30, 90:10.
2. The following steps are completely same as the first experiment. Then each individual plays the game with its neighbors, using the allocated strategy. In the spatial structure, every cell needs to play game with 3,or 5, or 8 neighbors according to their positions in the Lattice. Then the individual gain the payoff of itself (original payoff)

in the current generation.

3. After the game, each player needs to decide which strategy to adopt in the next generation, and this process is called evolution. The player first calculates the potential payoff for adopting a new strategy. Then the player compares the payoffs of the original strategy and the new strategy. Finally, it decides to change to the new strategy, or maintain the original choice.

4. Each individual evolves immediately after the comparison of the payoffs.

5. The system repeat the experiment for — times(generations).

V. Asymmetric Iterated HDG1 (All).

This experiment is also similar to Symmetric Iterated HDG1(All). It should be noted that the payoff matrix is different. The game process is described as follows:

1. At the beginning of the game, the system randomly chooses 30% individuals to represent the big companies, the remaining 70% represents the small companies. Then the system randomly and evenly distributed all strategies to 40000 players. Each strategy turns up with a equal probability, which is 5.56% in this project.

2. Then each individual plays the game with each of its neighbor iteratedly for 50 rounds, using the allocated strategy. In the spatial structure, every cell needs to play game with 3,or 5, or 8 neighbors according to their positions in the Lattice. Then the system records the average payoff of the players.

3. After all players have finished the contest, each player learns the best strategy from its neighbors. This means, the player compares the average payoffs of each of its neighbor, including itself, and adopts the strategy that with the highest average payoff.

4. The evolution step is carried out after all individuals in the Lattice have calculated and compared the average payoffs.

5. The system repeat the experiment for — times(generations).

VI. Asymmetric Iterated HDG2 (Compare). This experiment is also similar to Symmetric Iterated HDG2 (Compare). It should be noted that the payoff matrix is different. The game process is described as follows:

1. At the beginning of the game, the system randomly chooses 30% individuals to represent the big companies, the remaining 70% represents the small companies. Then the system randomly allocated two strategies to 40000 players. The game is carried out for five times with different initial proportion of the strategy 1 and the strategy2: 10:90, 30:70, 50:50. 70:30, 90:10.
2. Then each individual plays the game with each of its neighbor iteratedly for 50 rounds, using the allocated strategy. In the spatial structure, every cell needs to play game with 3,or 5, or 8 neighbors according to their positions in the Lattice. Then the system records the average payoff of the players.
3. After all players have finished the contest, each player learns the best strategy from its neighbors. This means, the player compares the average payoffs of each of its neighbor, including itself, and adopts the strategy that with the highest average payoff.
4. The evolution step is carried out after all individuals in the Lattice have calculated and compared the average payoffs.
5. The system repeat the experiment for — times(generations).

7 Results

7.1 Evaluation Methodology

As stated in the Experiment, the performance of a strategy is evaluated by the average payoff. This is the measurement for individuals to refer to. To evaluate the performance from the view of the whole environment (the economic market), we need to record and measure the the frequency of achieving the highest payoff, namely, the frequency of being learned by the neighbors[10]. In this project, we define the frequency as 'win rate'. If we apply this approach on all cells in the Lattice, we will find that the 'win rate' actually describes the space occupation ratio of a strategy. Therefore, the Lattice shows the 'win rate' visually by displaying the strategies with different colors:

7.2 Results of the Experiments

I. Symmetric Evolutionary HDG.

The experiment was carried for 50 runs for each ratio: 10:90, 10:90, 30:70, 50:50. 70:30, 90:10. The results show that the proportion of *Hawk* and *Dove* is approximately 50%:50%. The initial ratio of the *Hawk* and *Dove* do not significantly influence the outcome. The 50:50 ratio perfectly matches the ESS theory, where $p = V/C, p = 2/4 = 0.5$. The result shows that there is no pure strategy to reach the Nash equilibrium in an hawk-and-dove game. However, the ESS strategy which allocates strategies with the specific probability can reach the equilibrium. In this experiment, $H - D:\ 50 : 50$ is the mixed equilibrium strategy.

		ratio: 10:90		ratio: 30:70		ratio: 50:50		ratio: 70:30		ratio: 90:10	
		strategy1	strategy2	strategy1	strategy2	strategy1	strategy2	strategy1	strategy2	strategy1	strategy2
turn	0	0.5628	0.4372	0.5353	0.4647	0.4835	0.5165	0.4857	0.5143	0.4935	0.5065
turn	1	0.5565	0.4435	0.5254	0.4746	0.4876	0.5124	0.4854	0.5146	0.4875	0.5125
turn	2	0.548	0.452	0.5266	0.4734	0.4864	0.5136	0.4901	0.5099	0.4847	0.5153
turn	3	0.5568	0.4432	0.5296	0.4704	0.4865	0.5135	0.4892	0.5108	0.4915	0.5085
turn	4	0.5636	0.4364	0.5219	0.4781	0.4873	0.5127	0.4858	0.5142	0.4887	0.5113
turn	5	0.5458	0.4542	0.5284	0.4716	0.4862	0.5138	0.4859	0.5141	0.4925	0.5075
turn	6	0.5511	0.4489	0.5278	0.4722	0.4891	0.5109	0.4883	0.5117	0.4903	0.5097
turn	7	0.5535	0.4465	0.5192	0.4808	0.4854	0.5146	0.4889	0.5111	0.4868	0.5132
turn	8	0.5529	0.4471	0.5301	0.4699	0.4978	0.5022	0.4818	0.5182	0.4844	0.5156
turn	9	0.5501	0.4499	0.5248	0.4752	0.4897	0.5103	0.4871	0.5129	0.4911	0.5089
turn	10	0.5574	0.4426	0.5193	0.4807	0.4882	0.5118	0.4802	0.5198	0.4912	0.5088
turn	11	0.5614	0.4386	0.5203	0.4797	0.4875	0.5125	0.4884	0.5116	0.4859	0.5141
turn	12	0.5653	0.4347	0.5254	0.4746	0.4869	0.5131	0.4911	0.5089	0.4846	0.5154
turn	13	0.5747	0.4253	0.5293	0.4707	0.4861	0.5139	0.4862	0.5138	0.4831	0.5169
turn	14	0.5411	0.4589	0.534	0.466	0.4887	0.5113	0.493	0.507	0.4884	0.5116
turn	15	0.561	0.439	0.5296	0.4704	0.4842	0.5158	0.4873	0.5127	0.4875	0.5125
turn	16	0.5362	0.4638	0.5174	0.4826	0.4928	0.5072	0.4832	0.5168	0.4932	0.5068
turn	17	0.5678	0.4322	0.5292	0.4708	0.4967	0.5033	0.4814	0.5186	0.4887	0.5113
turn	18	0.5589	0.4411	0.5233	0.4767	0.4892	0.5108	0.4997	0.5003	0.4856	0.5144
turn	19	0.5754	0.4246	0.5259	0.4741	0.4849	0.5151	0.4866	0.5134	0.4891	0.5109
turn	20	0.5547	0.4453	0.526	0.474	0.4815	0.5185	0.4892	0.5108	0.4906	0.5094
turn	21	0.5686	0.4314	0.5234	0.4766	0.4861	0.5139	0.4855	0.5145	0.4943	0.5057
turn	22	0.5678	0.4322	0.5264	0.4736	0.4765	0.5235	0.4875	0.5125	0.4912	0.5088
turn	23	0.5472	0.4528	0.523	0.477	0.4867	0.5133	0.4891	0.5109	0.4755	0.5245
turn	24	0.5494	0.4506	0.5225	0.4775	0.4876	0.5124	0.4881	0.5119	0.4847	0.5153
turn	25	0.5606	0.4394	0.5228	0.4772	0.4851	0.5149	0.4811	0.5189	0.4747	0.5253
turn	26	0.5435	0.4565	0.5271	0.4729	0.4869	0.5131	0.4916	0.5084	0.4827	0.5173
turn	27	0.5631	0.4369	0.5282	0.4718	0.4838	0.5162	0.49	0.51	0.4879	0.5121

Figure 17: Results of SEHDG

II. Symmetric Iterated HDG1 (All).

In this experiment, we test all strategies together in a 200*200 Lattice. The experiments was carried out for 500 runs, and we record the final ratio of each strategies, namely the win rate. The results are shown as follows. We can see that the ratio of strategy *ALLC* and *FBF* are relatively the highest. In addition, *Pavlov* also performs well in this experiment. Moreover, tit-for-tat and the deformation of TFT also show good performance.

AllD	TFT	AllC	Grim	TFTT	STFT
0.0000%	10.4258%	13.1397%	7.7541%	5.8893%	0.0000%
Pavlov	Rand	NEG	TTFT	FBF	Gradual
9.3379%	0.0002%	0.0017%	3.3556%	11.8986%	7.7835%
Adaptive	C_TFT	G_TFT	Probe	Group	Group1
10.4197%	9.1562%	10.0603%	0.0418%	0.0544%	0.6809%

Figure 18: The final ratio of each strategy

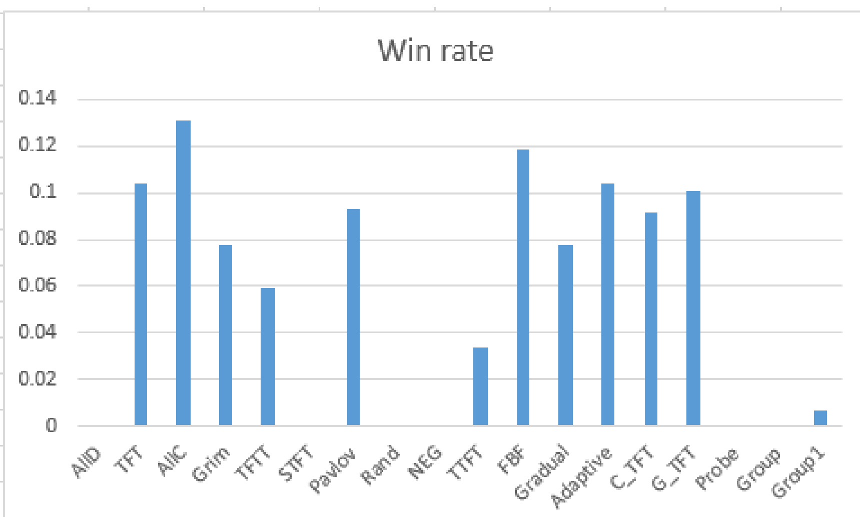

Figure 19: Win Rate

III. Symmetric Iterated HDG2 (Compare).

In this experiment, in order to compare the performance of two strategies, we measure the counter relationship between two strategies. I use a criteria table to visually show whether a strategy takes advantage over another one in a certain environment. The rule is that if the win rate of the *strategy A* is higher, then it is defined as a better counter-strategy for *strategy B*. For example, if the win rate of strategy A is 100%, and the win rate of strategy must be %0, then we say that *strategy A* is the best counter-strategy for the *strategy B*.

0%-40%	40%-60%	60%-100%
Bad	Neutral	Good

Figure 20: Criteria table

The results show that in some cases, the initial proportion of the strategies have large influence on the results, but some strategies are not susceptible to the initial ratio. Moreover, Group strategies are more easily to be affected by the initial proportion. Here we make a table to show the counter-relationship between the strategies.

strategy1/strategy2	AllD	TFT	AllC	Grim	TFTT	STFT	Pavlov	Rand	NEG	TTFT	FBF	Gradual	Adaptive	C_TFT	G_TFT	Probe	Group	Group1
AllD	/	Bad	Bad	Bad	Bad	DOR	Bad	Bad	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
TFT	Good	/	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	Good	DOR	DOR
AllC	Good	DOR	/	DOR	DOR	Good	DOR	Bad	Bad	DOR	DOR	DOR	DOR	DOR	DOR	Bad	Bad	Bad
Grim	Good	DOR	DOR	/	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
TFTT	Good	DOR	DOR	DOR	/	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
STFT	DOR	Bad	Bad	Bad	Bad	/	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
Pavlov	Good	DOR	DOR	DOR	DOR	Good	/	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	Good	Bad	DOR
Rand	Good	Bad	Good	Bad	Bad	Good	Bad	/	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
NEG	Bad	Bad	Good	Bad	Bad	Good	Bad	Bad	/	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
TTFT	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	/	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
FBF	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	/	DOR	DOR	DOR	DOR	Good	DOR	DOR
Gradual	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	/	DOR	DOR	DOR	DOR	DOR	DOR
Adaptive	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	/	DOR	DOR	Good	DOR	DOR
C_TFT	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	/	DOR	Good	DOR	DOR
G_TFT	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	/	Good	DOR	DOR
Probe	Good	Bad	Good	DOR	DOR	Good	Bad	Good	Good	DOR	Bad	DOR	Bad	Bad	Bad	/	DOR	DOR
Group	Good	DOR	Good	DOR	DOR	Good	Good	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	/	DOR
Group1	Good	DOR	Good	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR

Figure 21: Counter-relationship Table

Bad	where Strategy 2 takes advantage over Strategy 1
Neutral	where Strategy 1 and Strategy 2 evenly perform
Good	where Strategy 1 takes advantage over Strategy 2
DOR	where the relationship Denpends On the initial Ratio

Figure 22: Criteria table 2

IV. Asymmetric Evolutionary HDG.

he experiment was carried for 50 runs for each ratio: 10:90, 10:90, 30:70, 50:50. 70:30, 90:10. The results re shown below. We can see that the initial proportion of the strategies have slight influence on the results.In this experiment, the population is divided into two group: small companies and big companies. Therefore, besides the proportion among the whole population, we also analyze the strategy ratio in two groups respectively. However, after the calculations, the results show that the strategy proportion among the whole population is very close to the proportion among separate groups, and the difference is at most less than 2% for all trials. Therefore, we can know that the strategy adoption trend in two sub-groups is the same as the trend of the whole population.

ALL	ratio=10:90		ratio=30:70		ratio=50:50		ratio=70:30		ratio=90:10	
turn	strategy1	strategy2	strategy1	strategy2	strategy1	strategy2	strategy1	strategy2	strategy1	strategy2
0	0.6045	0.3955	0.5322	0.4678	0.4831	0.5169	0.4271	0.5729	0.353	0.647
1	0.5962	0.4038	0.5251	0.4749	0.4723	0.5277	0.4292	0.5708	0.3639	0.6361
2	0.6016	0.3984	0.5237	0.4763	0.4775	0.5225	0.4265	0.5735	0.3511	0.6489
3	0.603	0.397	0.521	0.479	0.4666	0.5334	0.4168	0.5832	0.3534	0.6466
4	0.5819	0.4181	0.5182	0.4818	0.4765	0.5235	0.4234	0.5766	0.3636	0.6364
5	0.5989	0.4011	0.5298	0.4702	0.4699	0.5301	0.4197	0.5803	0.3633	0.6367
6	0.6055	0.3945	0.5367	0.4633	0.474	0.526	0.4291	0.5709	0.3523	0.6477
7	0.5848	0.4152	0.5287	0.4713	0.4679	0.5321	0.4222	0.5778	0.3639	0.6361
8	0.6002	0.3998	0.522	0.478	0.4678	0.5322	0.419	0.581	0.3541	0.6459
9	0.593	0.407	0.5292	0.4708	0.4725	0.5275	0.4299	0.5701	0.3478	0.6522
10	0.6015	0.3985	0.5385	0.4615	0.4759	0.5241	0.4282	0.5718	0.3566	0.6434
11	0.6008	0.3992	0.5321	0.4679	0.4668	0.5332	0.4244	0.5756	0.3651	0.6349
12	0.6059	0.3941	0.5354	0.4646	0.4709	0.5291	0.4246	0.5754	0.36	0.64
13	0.5983	0.4017	0.5293	0.4707	0.4823	0.5177	0.4326	0.5674	0.3503	0.6497
14	0.5916	0.4084	0.5216	0.4784	0.4771	0.5229	0.4186	0.5814	0.3574	0.6426
15	0.5963	0.4037	0.5226	0.4774	0.4878	0.5122	0.4261	0.5739	0.3516	0.6484
16	0.6043	0.3957	0.5374	0.4626	0.4697	0.5303	0.4277	0.5723	0.3528	0.6472
17	0.6013	0.3987	0.5269	0.4731	0.4727	0.5273	0.4243	0.5757	0.3624	0.6376
18	0.5921	0.4079	0.5292	0.4708	0.478	0.522	0.4183	0.5817	0.3609	0.6391
19	0.5986	0.4014	0.5273	0.4727	0.4725	0.5275	0.4257	0.5743	0.355	0.645
20	0.5946	0.4054	0.5201	0.4799	0.4758	0.5242	0.4232	0.5768	0.3677	0.6323
21	0.5959	0.4041	0.527	0.473	0.4824	0.5176	0.4298	0.5702	0.3541	0.6459
22	0.6059	0.3941	0.5145	0.4855	0.4739	0.5261	0.4312	0.5688	0.3603	0.6397
23	0.5989	0.4011	0.5233	0.4767	0.4786	0.5214	0.4275	0.5725	0.3604	0.6396
24	0.5928	0.4072	0.5329	0.4671	0.4713	0.5287	0.4288	0.5712	0.3582	0.6418
25	0.5958	0.4042	0.5356	0.4644	0.4767	0.5233	0.4257	0.5743	0.3619	0.6381

Figure 23: Results of AEHDG

V. Asymmetric Iterated HDG1 (All).

In this experiment, we test all strategies together in a 200*200 Lattice. The experiments was carried out for 450 runs, and we record the final ratio of each strategies, namely the win rate. In addition, win rate among small companies and big companies are also evaluated. The results are shown as follows. We can see that the ratio of strategy $ALLC$ and FBF are relative the highest. In addition, $Pavlov$ also performs well in this experiment. Moreover, tit-for-tat and the deformation of TFT also have good performance.

	AllD	TFT	AllC	Grim	TFTT	STFT
strategy	0.1868%	9.9564%	9.6512%	7.4622%	6.4832%	0.1897%
small company	0.1868%	9.9578%	9.6552%	7.4518%	6.4833%	0.1898%
big company	0.1868%	9.9529%	9.6421%	7.4865%	6.4828%	0.1894%
	Pavlov	Rand	NEG	TTFT	FBF	Gradual
strategy	9.8791%	0.2344%	0.2589%	4.7374%	11.0060%	7.2800%
small company	9.8819%	0.2342%	0.2586%	4.7411%	11.0004%	7.2821%
big company	9.8729%	0.2344%	0.2595%	4.7296%	11.0190%	7.2750%
	Adaptive	C_TFT	G_TFT	Probe	Group	Group1
strategy	9.9779%	9.9522%	9.9333%	1.6737%	0.3374%	0.8006%
small company	9.9752%	9.9558%	9.9312%	1.6763%	0.3375%	0.8004%
big company	9.9843%	9.9436%	9.9377%	1.6674%	0.3366%	0.8008%

Figure 24: The final ratio

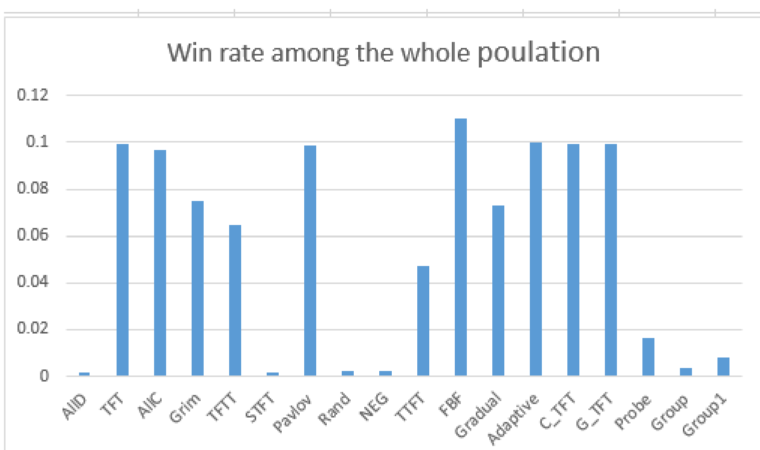

Figure 25: Win Rate

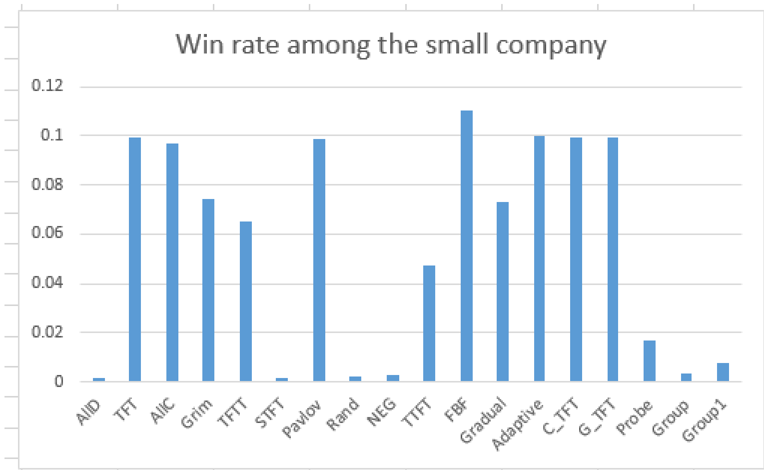

Figure 26: Win Rate

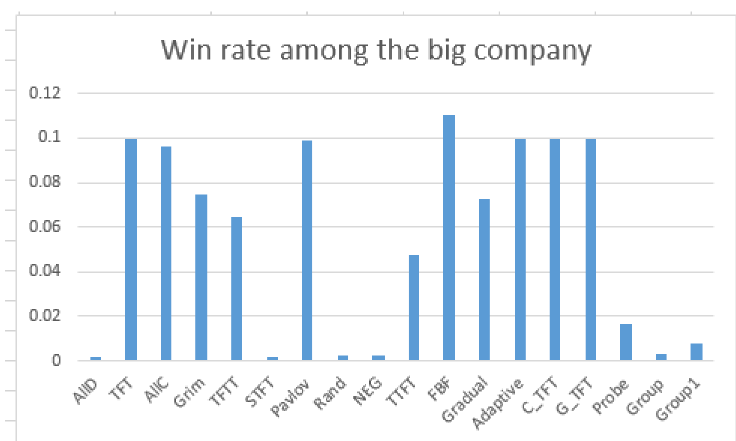

Figure 27: Win Rate

VI. Asymmetric Iterated HDG2 (Compare).

In this experiment, we use the same evaluation method in the Experiment III. We compare the proportion of two strategies, and analyze the counter-relationship between them. The difference is that in this experiment the population is divided into two group: small companies and big companies. Therefore, besides the proportion among the whole population, we also analyze the strategy ratio in two groups respectively. However, after the calculations, the results show that the strategy proportion among the whole population is very close to the proportion among separate groups, and the difference is less than 1% for all trials. Therefore, we can know that the strategy adoption trend in two sub-groups is the same as the trend of the whole population. Here is the table for all companies. The tables for small companies and big companies are same as this one.

strategy1/s	AllD	TFT	AllC	Grim	TFTT	STFT	Pavlov	Rand	NEG	TTFT	FBF	Gradual	Adaptive	C_TFT	G_TFT	Probe	Group	Group1
AllD	/	Bad	Bad	Bad	Bad	DOR	Bad	Bad	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
TFT	Good	/	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
AllC	Good	DOR	/	DOR	DOR	Good	DOR	DOR	Bad	DOR	DOR	DOR	DOR	DOR	DOR	Bad	Bad	Bad
Grim	Good	DOR	DOR	/	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
TFTT	Good	DOR	DOR	DOR	/	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
STFT	DOR	Bad	Bad	Bad	Bad	/	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
Pavlov	Good	DOR	DOR	DOR	DOR	Good	/	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
Rand	Good	Bad	DOR	Bad	Bad	Good	Bad	/	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
NEG	Bad	Bad	Good	Bad	Bad	Good	Bad	Bad	/	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
TTFT	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	/	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR
FBF	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	/	DOR	DOR	DOR	DOR	DOR	DOR	DOR
Gradual	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	/	DOR	DOR	DOR	DOR	DOR	DOR
Adaptive	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	/	DOR	DOR	DOR	DOR	DOR
C_TFT	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	/	DOR	DOR	DOR	DOR
G_TFT	Good	DOR	DOR	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	/	DOR	DOR	DOR
Probe	Good	DOR	Good	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	/	DOR	DOR
Group	Good	DOR	Good	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	/	DOR
Group1	Good	DOR	Good	DOR	DOR	Good	DOR	Good	Good	DOR	DOR	DOR	DOR	DOR	DOR	DOR	DOR	/

Figure 28: Counter-relationship Table for Asymmetric game

Bad	where Strategy 2 takes advantage over Strategy 1
Neutral	where Strategy 1 and Strategy 2 evenly perform
Good	where Strategy 1 takes advantage over Strategy 2
DOR	where the relationship Denpends On the initial Ratio

Figure 29: Criteria table 2

8 Discussion & Conclusion

In conclusion, this project builds an agent-based model to simulate the competition-cooperation behaviors in a economic market based on hawk-and-dove game. The system analyzes the performance of various strategies in different models. Each model represents a specific scenario in the market. In addition, win rate and criteria table are applied to measure the performance of the strategies.

The results show that in evolutionary games where each company is considered with equal wealth, strength, and power, the ESS always dominates the whole population. In iterated games, some strategies such as $AllC$, $titfortat$ show good performance. However, though group strategies perform well in the prisoners' dilemma, it seems they do not have advantages in the hawk-and-dove game. In addition, the results of asymmetric games are similar to the results of symmetric game, but little difference still exists.

9 Implementation

9.1 Programming Tool

C is used as the main programming language for the project. The primary development tool is Visual Studio C++. which is a widely used integrated development environment (IDE) for C and C++ program. It is an IDE with plenty of features and support editing, debugging, building code and publishing software. Compilers, code completion tools, graphical designers are included for development service.

9.2 Interface

In order to simulate the spatial game, we display a 200*200 Lattice to show the evolution process. There are 40000 cells evenly distributed on the Lattice, where represents a single agent with a selected strategy. Each player are set with a specific color according to the strategy they adopt. For example, in this project, the color *Green* represents the strategy *AllD*, and the color *Red* represents the strategy *AllC*. Then the agent who adopt *AllD* will be displayed as a small green dot, and the agent who adopt *AllD* will be displayed as a small red dot.

EasyX Graphics Library is used to support the graphic display in this project. It is a free drawing library for Visual C + +, which supports VC6.0   vc2019. In order to run the program successfully, the library *graphics.h* needs to be included in the head file.

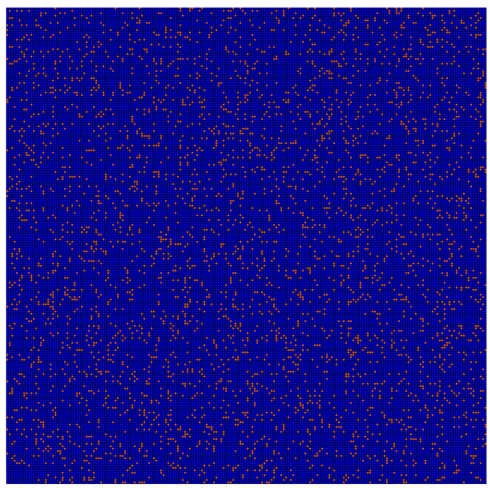

Figure 30: Interface

9.3 Data processing

The data processing is carried out after the experiment when the results have been output. In the first step, the result data are recorded in *txt* files. Then, we use the Office tool Excel to do the data processing. Excel provides many mathematics formulas that support performing fundamental calculations of large amounts of data, such as calculating the average value, the standard deviation, finding the maximum value, etc.

9.4 Result Presentation

In order to visually demonstrate the results, we use the graphic drawing tools embedded in Excel.Charts and graphs help the data presentation to be more compelling, with well-designed foramtting and sparklines. The visual diagrams enables users to better understand the data.

Figure 31: Excel

10 Project Management

This chapter discusses the project management, including the schedule arrangement plan, the important deadlines, and the schedule progress tracking.

10.1 Important Deadlines

1. Project proposal: October.23
2. Interim report: December.11
3. Final report submission: April.26
4. Video recording submission: May.3

5. Question and answer session: May.11

10.2 Schedule Plan and Progress

The overall project takes seven months in total from Oct. 9 in 2020 to April.26 in 2021. Several plans have been remade because of the current progress was too slow to catch the schedule plan. The actual progress is very different from the original version of the plan. The Gannt chart below show the gap between the plan and the actual progress.

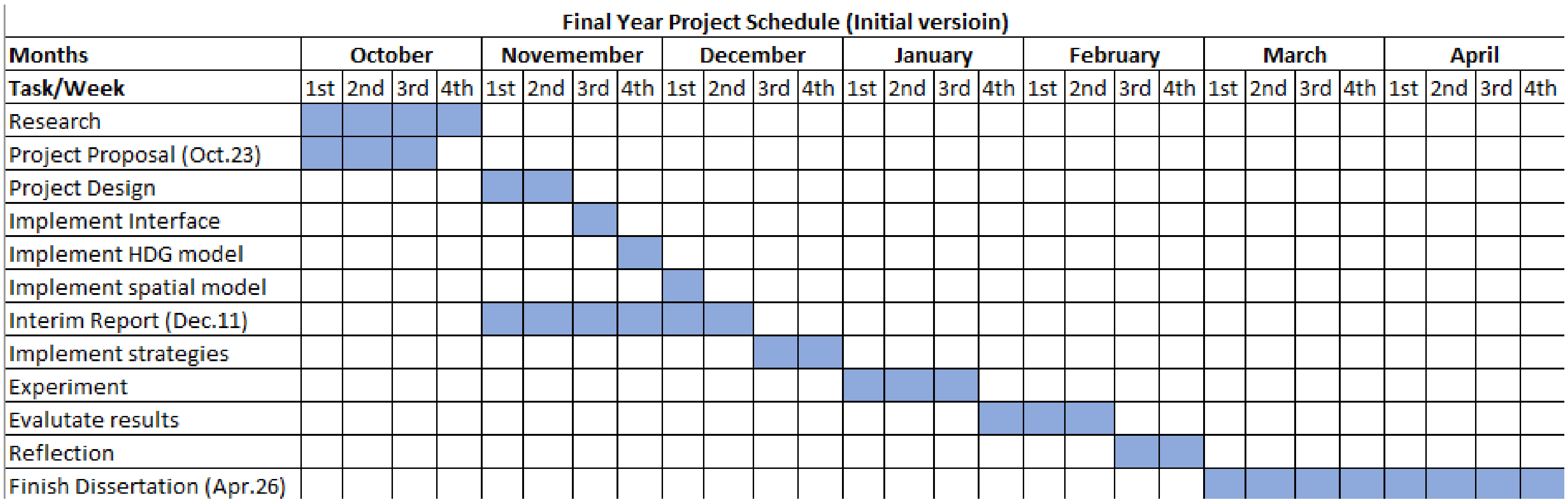

Figure 32: Initial schedule

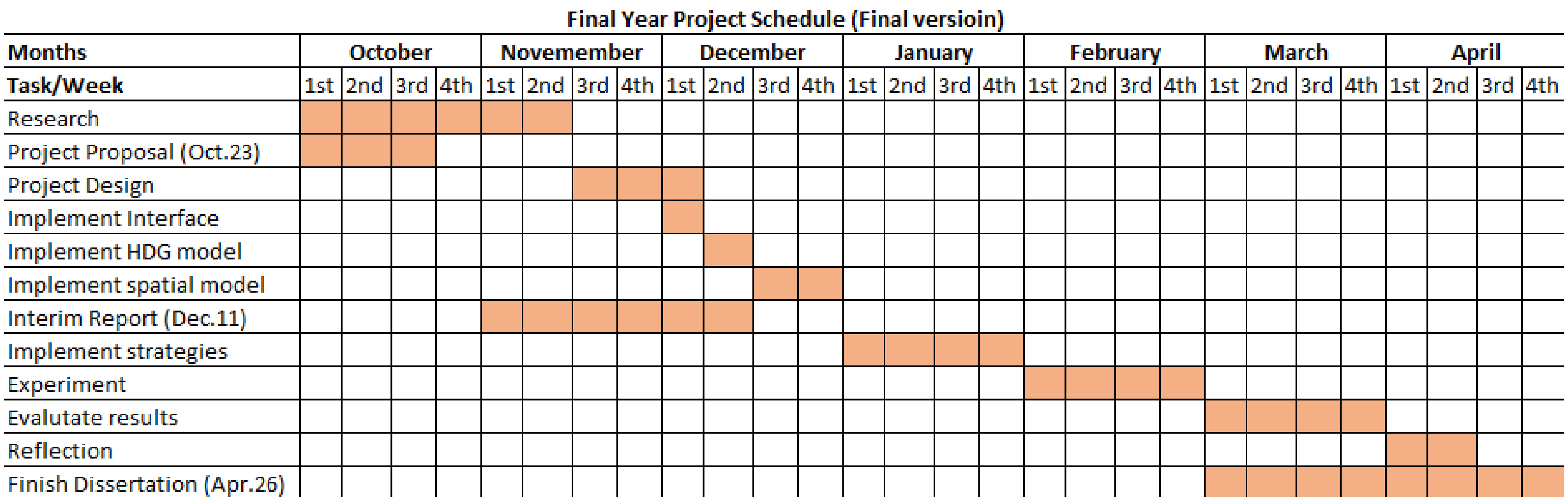

Figure 33: Final schedule

11 Reflection

11.1 Reflection on project completion

All objective tasks have been successfully completed. The design of the program and the experiments have been well established, and the coding has been finished in a concise and readable style.However, some problems still need to be solved. Firstly, the number of experiments are not enough due to the time limits. Although the results show that there is little difference between repeated experiments, it is necessary to carry out more trials. Massive experiments can reduce the error, improve the accuracy, as well as increase the preciseness. Secondly, in evolutionary game experiments, the traditional repeated game (not spatial)is applied for the evaluation. However, during the experiment, I found that the spatial evolutionary game results are very different from the traditional ones. However, due to the time limits, I haven't done enough experiments to figure out the cause of the difference. Thirdly, the operating efficiency is too low to execute a program with higher complexity. It requires long time to execute a complete task.

Key objectives	Status
1. Develop a simulation program using agents and spatial game structure.	Complete
2. Develop evolutionary hawk-and-dove model, iterated hawk-and-dove model and asymmetric hawk-and-dove model.	Complete
3. Select potential strategies, carry out experiments to identify well-performed strategies.	Complete
4. Evaluate strategies performance and robustness in different models.	Complete
5. Elicit the practical meaning of the project in economic areas.	Complete

Figure 34: Task Compeletion

11.2 Reflection on project management

The first version project schedule is proved to be appropriate, as the majority of the deadlines are strictly met and the average working hours for each week are close. However, some tasks was postoned because of the workload of other subjects. Fortunately, the slight delay did seriously affect the quality of the demonstration of achievements and report writing.Therefore, to ensure the process moving forward within the schedule, it is necessary to allow extra time that can fill in the missing work. It is also necessary to leave longer time for the most challenging part of the whole project.

12 Future Study

In the real market, the company composition and proportion are more complicated. There are various enterprises of different sizes in the market, not only big companies and small companies. Therefore, the asymmetric model proposed in this project is not sufficiently accurate to describe the actual competition-cooperation law in the economic market.

In the future study, we should first establish a dynamic asymmetric model based on mathematical functions. The payoff matrix should change over time according to the size of the company as well as its opponent. In this case, every two enterprises with different sizes should match a specific payoff matrix. Moreover, the size of a company should also change over time. The company will become more powerful or weaker according to the payoff it gained in the last generation.

Certainly, the realization of this design is challenging. The difficulty is mainly due to the fact that the relationship between payoff matrix and the size of interactive enterprises is difficult to be accurately described by simple functions. In theory, first, the function relationship needs to be derived from a perfect statistical mathematical model or trained by machine learning. Secondly, the change rate of enterprise size needs a lot of statistical data as support.

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