JEALOUSY IN COOPERATION – A COMPARISON OF TWO GAME BASED APPROACHES

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We are interested in the question of how to motivate people to share valuable information, so that group performance can be leveraged. In a previous article we investigated the impact of power and jealousy on cooperation. By using intelligent agents, a stochastic updating process has been used, so that artificial agent populations could be modelled. In the current article we investigate update procedures based on deterministic dynamics for populations arranged in a lattice. Compared to stochastic processes our findings show that populations behave and react far more dynamically, in certain parameter regions, when spatial cooperation is applied.

1. Introduction

Collaboration plays an important role in highly developed societies. We investigate the impact of jealousy on cooperation. In a previous study (Barachini, 2015) we used stochastic updating procedures and the business transaction theory (Barachini, 2007, 2009) for our investigations. In this study, we investigate the deterministic evolutionary dynamics of populations, which are arranged in a lattice. We concentrate our effort on the question how jealous agents can invade co-operators and vice versa. We show how complex patterns are generated in certain parameter regions, when spatial cooperation in finite populations is applied. We compare this approach with the stochastic one.

2. Background

Emotions play a big role during cooperation. Jealousy seems to play a special role (Barachini, 2015; Brockner, 1988; Pelham *et al.*, 1989; Rydell *et al.*, 2007). We investigate a game theoretical approach, how jealous agents can invade co-operators and vice versa.

2.1. The notion of jealousy

Cooperation through information sharing is substantially influenced by an individual's level of jealousy. This concept so far has been discussed most often in the context of close relationships. This emotion also plays an important role in the work context. The loss or merely the perceived threat of a loss involves the perception of a rival's intrusion. This rival has the potential to reduce one's self-esteem or undermine a valued relationship. It is hence a characteristic of jealousy that it is triadic, involving the focal individual, the rival, and the valued target person.

to the emotional components of jealousy. *Suspicious jealousy* contains cognitive and behavioural components. They argue that manifestations and antecedents differ for these two types. Specifically, reactive jealousy that occurs after a major jealousy-evoking event and is thus more closely related to exogenous factors, appears to be positively related to trust, and negatively related to chronic jealousy. However, suspicious jealousy that occurs before major jealousy-evoking events have occurred (Rydell, Bringle 2007) is more closely related to endogenous factors and is positively associated with insecurity and chronic jealousy, and negatively associated with self-esteem, i.e. an individual's self-evaluation of its own competencies (Rosenberg 1965), including an affective component of liking itself (Pelham, Swan 1989). It has been found to positively influence employee attitudes such as job satisfaction, motivation, and performance (e.g. Brockner 1988).

We assume that suspicious jealousy plays an important role in collaboration by mediating the relationship between self-esteem and the willingness to share knowledge with a person who is a potential rival such, that the less self-esteem an individual has, the more they may show suspicious jealousy toward potential rivals and the less they will be willing to share their knowledge with those. Reactive jealousy, in turn, may negatively influence cooperative behaviour only after the occurrence of an event that has evoked an individual's jealousy.

In our simulations we investigate suspicious jealousy for two reasons. Firstly, it is easy to implement because we use simple matrices for payoff calculations and secondly, reactive jealousy would impose much more complexity, because we would have to construct specific artificial social injustice examples. However, in real life, reactive jealousy is much better identifiable than suspicious jealousy. Reactive jealousy can easily be detected because of its exogenous nature. The detection of suspicious jealousy needs deeper psychological investigations.

2.2. Cooperation methods and modelling – state of the art

Cooperation implies, a donor pays a cost and a recipient gets a benefit in the short term. In the long term the relation should be balanced. However, cooperation is always vulnerable to exploitation by defectors. Researchers identified well established cooperation rules, such as, e.g. kin selection and related schemes (Hamilton 1964a, 1964b, 1996, 2001), graph and group selection and related schemes (Ohtsuki, Iwasa 2004; Ohtsuki et al.), indirect reciprocity, and spatial evolutionary game theory. Among others, punishment and cooperation were investigated by Sigmund et al, (Sigmund, Hauert and Nowak, 2001). However, Conte et al. (Conte R, Castelfranchi C, Pedone R, 1999) proved, that prisoner dilemma games (Axelrod, 1984) cannot account for a theory of cooperation, since bargaining is not possible. Therefore, in a previous research we applied an interdisciplinary approach based on the business transaction theory, Barachini (Barachini, 2007). He underpins the theory in a broad industry survey (150 European companies, three countries) published in JKM (Barachini, 2009). Similarly to Akerlof (Akerlof, 1970), Spence (Spence, 1973), and Stiglitz (Stiglitz, 1975), the theory is based on the idea, that information is asymmetric in its nature.

Although Conte criticized the approach of using prisoner's dilemma games because bargaining is not possible, we apply a game theoretical approach and we compare this deterministic spatial approach with the stochastic one.

3. Methodology

In the stochastic approach members of a population meet each other randomly. In the

spatial approach members of a population are arranged in a two or higher dimensional array. In each round every individual, represented by a cell, plays a game with its immediate neighbors. After the game, each cell is occupied by its original owner or by one of the neighbors, depending on who scored the highest payoff in that round.

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On a spatial multi-dimensional grid each player occupies a position on the grid, the cell, and interacts with all of its neighbors. In normal life a player can select from an infinite number of strategies. In a deterministic spatial game each player adopts the strategy with the highest payoff in its neighborhood. The players are updated in synchrony.

The fate of a cell depends on its own strategy, the strategy of its neighbours, and the strategy of their neighbours. If we consider a 3-dimensional cube containing 5 x 5 mini cubes per surface and we observe the inner cube, then the fate of this inner cube depends on its own strategy, the strategies of its 26 neighbours ($3 \times 3 \times 3 - 1$) and the strategies of their 98 neighbours (the outer layer of the $5 \times 5 \times 5$ cube). Thus, 125 cells in total determine what will happen to the inner cell of a cube.

To make it easier for the reader, we show experiments with 2 dimensional arrays only. In this case, each cell has 8 direct neighbors. Thus, 25 cells in total determine what will happen to a cell. To repeat, a player represented by a cell, will retain its current strategy, if it has a higher payoff than all of its neighbors. Otherwise, the player will adopt the strategy of that neighbor with the highest payoff.

In our examples we simulate players with 3 characteristics only. That means, a player can choose between 3 strategies. We have defectors (D), co-operators (C) and conditional co-operators (CC). The latter represent jealous co-operators. The level of jealousy is determined by α respectively by γ of the payoff matrix in Figure-1. Both values vary between 0 and 1. The higher both values are, the higher the probability of cooperation, the lower the jealousy factor. Consequently, a player can choose between the three strategies C, D and CC. The numbers in the following payoff matrices preceding the colon represent the payoff given to the line player and the numbers after the colon represent the payoff given to the column player.

	C	D	CC
C	1, 1	0, a	$\gamma, \gamma + (1-\gamma)a$
D	a, 0	ε, ε	$\gamma a + (1-\gamma)\varepsilon, (1-\gamma)\varepsilon$
CC	$\alpha + (1-\alpha)a, \alpha$	$(1-\alpha)\varepsilon, \alpha a + (1-\alpha)\varepsilon$	$\gamma \alpha + (1-\alpha)\gamma a + (1-\alpha)(1-\gamma)\varepsilon, \gamma \alpha + (1-\gamma)\alpha a + (1-\alpha)(1-\gamma)\varepsilon$

Figure-1: Payoff matrix

The payoff matrix of Figure-1 can be interpreted as follows. If two co-operators interact, then both receive one point. If a defector meets a co-operator, the defector gets a payoff $a > 1$ and the co-operator gets the payoff zero. The interaction between two defectors leads to a very small positive payoff ε , for both. If a co-operator meets a conditional co-operator, then the co-operator gets payoffs between 0 and 1 and the conditional co-operator gets payoffs between 1 and a, with $a > 1$. If a conditional co-operator meets a defector, then the conditional co-operator gets payoffs between 0 and ε and the defector gets payoffs between ε and a. When two conditional co-operators meet, then they both have a payoff range in between 0 and a, $a > 1$.

In case of setting α to 1 or 0 and setting γ to 1 or 0, we get the simple matrix consisting only of co-operators (C) and defectors (D). Since we simulate jealousy by the parameters α and γ , more jealousy means less cooperation, we have to keep the matrix above, but for simplicity we choose to set $\varepsilon \rightarrow 0$. In fact, this simplification of the matrix in Figure-1 yields the matrix of Figure-2, which represents a prisoner dilemma. To explore different evolutions of populations, we vary the parameters a , α and γ . We perform our experiments by investigating suspicious jealousy only, because we would have to construct specific artificial social injustice examples, so that reactive jealousy could be investigated. This would make our simulations even more complex.

	C	D	CC
C	1, 1	0, a	$\gamma, \gamma + (1-\gamma)a$
D	a, 0	0, 0	$\gamma a, 0$
CC	$\alpha + (1-\alpha)a, \alpha$	0, αa	$\gamma\alpha + (1-\alpha)\gamma a, \gamma\alpha + (1-\gamma)\alpha a$

Figure-2: Simplified payoff matrix

Modeling of suspicious jealousy in the deterministic spatial approach is performed by varying the parameters α and γ . Since their values vary in between 0 and 1 with a >1 , this is a huge mathematical space, our simulation results fill more than thousand books. Therefore, we present an extract of all possible outcomes by discussing some interesting parameter regions.

3.1. Co-Operators invaded by defectors

Individuals of the populations are placed in the two dimensional lattice. The problem can be regarded as an evolutionary game theoretical problem. The standard procedure therefore would be, to explore the conditions for invasion. We investigate the conditions for a single defector to invade a population of co-operators. Note, that a co-operator could be of type C (unconditional cooperation) or CC (conditional cooperation, based on the level of suspicious jealousy).

6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	
6,48 + 0,72 a	5,67 + 0,63 a	5,67 + 0,63 a	5,67 + 0,63 a	6,48 + 0,72 a	
6,48 + 0,72 a	5,67 + 0,63 a	7,2 a	5,67 + 0,63 a	6,48 + 0,72 a	
6,48 + 0,72 a	5,67 + 0,63 a	5,67 + 0,63 a	5,67 + 0,63 a	6,48 + 0,72 a	
6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	

Figure-3: Payoffs of a single defector cell and of the surrounded jealous co-operator cells

Figure-3 shows the conditions for a single defector to invade a population of jealous co-operators. We set the level of suspicious jealousy to 10 %, that means the cooperation levels of α and γ are set to 0.9. Based on the payoff matrix from Figure-2, we can evaluate the payoff of the single defector (red cell). The single defector is surrounded by 8 jealous co-operators (blue cells). Therefore, the payoff of the defector is 8 times the D-CC combination ($8 \times \gamma \times a$) plus one D-D combination. Since the D-D combination yields 0, we get $8 \times 0,9 \times a = 7,2 a$. Therefore, the red cell has payoff 7,2 a.

The blue cell above the red cell is a jealous co-operator and it is surrounded by 7 other blue cells and one red cell. Therefore, the payoff of the jealous co-operator is 7 times the CC-CC combination ($7 \times (0,9 \times 0,9 + 0,1 \times 0,9 \times a)$) plus one CC-D combination. Since the CC-D combination yields 0, we get “5,67 + 0,63 a” for this blue cell. Similarly all the

other cells are filled in by using the payoff matrix of Figure-2.

If “ $7,2 a > 6,48 + 0,72 a$ ”, which means $a > 1$, then the defector will take over all its neighbor cells. This will than yield Figure-4.

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6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a
6,48 + 0,72 a	5,67 + 0,63 a	4,86 + 0,54 a	4,05 + 0,45 a	4,86 + 0,54 a	5,67 + 0,63 a	6,48 + 0,72 a
6,48 + 0,72 a	4,86 + 0,54 a	4,5 a	2,7 a	4,5 a	4,86 + 0,54 a	6,48 + 0,72 a
6,48 + 0,72 a	4,05 + 0,45 a	2,7 a	0	2,7 a	4,05 + 0,45 a	6,48 + 0,72 a
6,48 + 0,72 a	4,86 + 0,84 a	4,5 a	2,7 a	4,5 a	4,86 + 0,84 a	6,48 + 0,72 a
6,48 + 0,72 a	5,67 + 0,63 a	4,86 + 0,54 a	4,05 + 0,45 a	4,86 + 0,54 a	5,67 + 0,63 a	6,48 + 0,72 a
6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a	6,48 + 0,72 a

Figure-4: 9D Square

In Figure-4, the central defector has a payoff of zero and the rest is evaluated using our payoff matrix from figure-2.

- The 9D square defector cells will turn into a single defector again, if “ $4,86 + 0,54 a > 4,5 a$ ”. Thus, if “ $1,22 > a$ ”, then figure-4 will again turn into Figure-3.
- The 9D square stays stable, if “ $6,48 + 0,32 a > 4,5 a > 5,67 + 0,63 a$ ”. Thus, if “ $1,71 > a > 1,46$ ”, then the configuration of Figure-4 will not change.
- There will be further growth of the 9D Square, if “ $4,5 a > 6,48 + 0,32 a$ ”. Thus, if “ $a > 1,55$ ” we have further linear growth of the 9D square to a 25D square, and so on, until eternity.
- Figure-4 will turn into the cross of Figure-5, if “ $5,67 + 0,63 a > 4,5 a > 4,86 + 0,54 a$ ”. Thus, if “ $1,46 > a > 1,22$ ” we get a cross, which will turn again into a single defector of figure-3. In this case we have a period two oscillator.

	6,48 + 0,72 a	5,67 + 0,63 a	5,67 + 0,63 a	5,67 + 0,63 a	6,48 + 0,72 a	
	5,67 + 0,43 a	4,05 + 0,45 a	4,5 a	4,5 + 0,45 a	5,67 + 0,63 a	
	5,67 + 0,63 a	4,5 a	3,6 a	4,5 a	5,67 + 0,63 a	
	5,67 + 0,63 a	4,05 + 0,45 a	4,5 a	4,05 + 0,45 a	5,67 + 0,63 a	
	6,48 + 0,72 a	5,67 + 0,63 a	4,05 + 0,45 a	5,67 + 0,63 a	6,48 + 0,72 a	

Figure-5: Cross

The above example is only one of many million and it shows one deterministic pattern. Many more deterministic patterns have been observed. We also simulated jealous co-operators invading defectors. It is strongly dependant on the value of a (the reward) and the values of γ and α , whether the world is dominated by defectors or by co-operators or, whether there is a dynamic balance. In certain parameter regions the abundance of jealous co-operators depends on the starting configuration of the grid. In other parameter regions the frequency of co-operators is almost constant, especially in very large arrays.

The simulations are all based on finite automata. There is one very interesting constellation, where dynamic kaleidoscopes and fractals are generated. The initial conditions for these kaleidoscopes are shown in Figure-6.

				$6,48 + 0,72 a$	
		$4,05 + 8,45 a$	$4,86 + 0,54 a$	$5,67 + 0,63 a$	
		$2,7 a$	$4,5 a$		
		0			

Figure-6: Conditions for fractals and kaleidoscopes

- If " $4,5 a > 6,48 + 0,72 a$ ", then defectors win at corners. That means, $a > 1,71$.
- If " $2,7 a < 4,05 + 0,45 a$ ", then jealous co-operators win along lines. That means, $a < 1,8$.
- Thus, if " $1,8 > a > 1,71$ ", then we have a clash of extremes.

Figure-7 and Figure-8 show the fractals after 124 and after 128 rounds for the parameter a , using a jealousy factor of 10% for each co-operator on a 128×128 spatial grid. We started with a single defector. Only by coloring the grid, the pattern can be optically observed:

- yellow is a defector, that was a jealous co-operator in the previous round;
- green is a jealous co-operator, that was a defector in the previous round;
- red is a defector, that was a defector in the previous round,
- blue is a jealous co-operator, that was a jealous co-operator in the previous round.

Figure-7: Kaleidoscope after 124 Update rounds

Figure-8: Kaleidoscope after update 128 rounds

In figure-7 and Figure-8, the fractals repeat themselves at the power of 2. It can be observed, that the number of defectors converges towards $2/3$. This can be observed after many thousand rounds. The jealous co-operators cannot be totally invaded by defectors.

3.2. Defectors invaded by co-operators

For “ $1,8 > a > 1,71$ ”, we show in Figure-9 a fractal after 260 rounds, using a jealousy factor of 50% for each co-operator. We used again a 128×128 spatial grid, representing a population size of 16384 cells. We started with a 9D block of co-operators within defectors:

- white is a defector, that was a jealous co-operator in the previous round;
- blue is a jealous co-operator, that was a defector in the previous round;
- red is a defector, that was a defector in the previous round,
- dark is a jealous co-operator, that was a jealous co-operator in the previous round.

Figure-9: Fractal after 256 update rounds

In Figure-9, the fractals repeat themselves at the power of 2. It can be observed, that the number of defectors converges towards $2/3$. The defectors cannot be invaded by jealous co-operators.

3.3. *Architecture used for both approaches*

As explained in Barachini (Barachini, 2015) in the stochastic approach, we used many modules of our own Java based architecture. Figure-10 shows the basic modules. The architecture allows studying the impact of emotions to cooperation models, by using dynamic artificial agents and agent populations following combined characteristics.

The payoff matrices, as they are used in the evolutionary game theory and presented in this paper, are used in the module “Game theory”, which actually is implemented as a link to an extern module known as “VirtualLabs”, which is publically available at the University Vienna. The module “marker technologies” has not yet been implemented, since we are experimenting with artificial agents and not persons.

Figure-10: Architecture

4. Discussion and Findings

In this article we investigated update procedures based on deterministic dynamics, in a spatial grid. In a previous article, we used stochastic updating procedures. One result of the previous investigations (Barachini, 2015) is shown in Table-1.

Table-1: Stochastic Updating

	100 rounds			500 rounds			10 000 rounds		
	egoists	jealous coop.	uncond. coop.	egoists	jealous coop.	uncond. coop.	egoists	jealous coop.	uncond. coop.
Population Size									
100	1	29	70	1	0	99	1	0	99
1000	10	439	551	9	389	602	9	0	991
10000	100	4890	5010	100	4681	5219	97	0	9903

Analyzing Table-1, we observe, that there is a convergence, even in very large populations. With small population sizes up to 100 individuals stability is achieved after 500 rounds. With larger population sizes, the system needs more rounds, so that a stable state can be reached. Note that stability is not always achievable, but in general much more update rounds and bigger population sizes tend to eliminate jealous co-operators. In general, if update rules are defined by stochastic update procedures, then there will be three absorbing states: equilibrium between co-operators and defectors, all co-operators or all defectors. Egoists in this case are defectors.

If update rules are determined by deterministic dynamics, as defined in this article, then we can even produce fractals and kaleidoscopes, which repeat themselves at the power of 2 and where all types of cells can find their place. Thus, jealous cells are not eliminated under specific parameter conditions. This is a special case of equilibrium. However, fractals and kaleidoscopes cannot be produced with stochastic update rules, because they do not maintain symmetry.

We conclude that under special constellations of the cells, the presented spatial game theoretical approach has a higher variety in dynamical behaviors than the stochastic one. This variety mainly depends on the payoff function, which is determined by the intensities of the reward and of suspicious jealousy, and a very specific constellation of edge and line cells in the grid. Whether less or more reward is needed, depends on the jealousy level. The parameter regions are shifted accordingly.

If the level of jealousy would be determinable in real life, then we could make estimations of the collective behavior of groups, and even then it could be chaotic. But is a chaotic behavior dangerous for groups and their managers? Yes and no! Kaleidoscopes indeed make the impression of chaos, but in the long run, the numbers of co-operators and defectors stay balanced. In spite that jealous co-operators are switching continuously from one cell to the next, the equilibrium of the group might not be endangered. Therefore, the other parameter regions could be more relevant for real life investigations, since they can tip populations completely, as it was explained in figure-4 for the 9D square, with the parameter region " $a > 1,55$ ".

5. Conclusion and Future Work

In our experiments suspicious jealousy, unconditional cooperation readiness (trust) and egoism (defection) are investigated. During the investigations, we applied stochastic and deterministic game theoretical approaches, applied to artificial agents.

We suspect that behavior of humans in groups is still more complex, since beside egoism, trust and jealousy, additional emotions, such as joy, fear, surprise, anger or anticipation need to be considered. It is very hard to control emotions during experiments with humans and to identify root-cause effects trigger by these emotions. Moreover, in reality it is probable impossible to identify people and measure their exact levels of suspicious jealousy. This type of jealousy can be regarded as a typical disease pattern. In order to establish unambiguous psychological experiments with humans, all these facts need to be considered.

In real life a mixture of stochastic and spatial interactions occurs. In highly automated companies, with fixed defined processes and few customer contacts, spatial internal interaction in the production line is probably dominant.

The experiments with artificial agents positioned in a lattice and using deterministic update procedures show, that in certain special cases, an even much more dynamic behavior of populations can be generated, than with stochastic update procedures. We simulated suspicious jealousy by simply modifying the two parameters α and γ . The level of jealousy influences social behavior and group structures, as it has been shown in the colored pictures.

In the previous stochastic analysis (Barachini, 2015), we used specific games which are not identical to the deterministic spatial game based approach. In the deterministic approach, we used a simple matrix representing prisoner dilemmas. We used 2 dimensional grids only. More research with multi dimensional grids and with different starting configurations can be done. Instead of synchronous updating, one could also investigate asynchronous updating of cells, where overlapping generations and therefore, even more complexity could arise.

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