Segregation in social dilemmas

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Résumé

One question in the social sciences has been to explain the observation of large difference in outcomes such as the appearance of criminal zones in the absence of commensurate difference in fundamentals. We show that a part of the puzzle in social dilemmas lies in the spatial structure of interactions. Segregation between cooperative and non cooperative zones may emerge as a function of sample size and type of interaction. The modelling is an extended prisoner's dilemma which suppose two additional features related to observations in experimental economics. First people differ in their preferences : the majority of people are either pure egoists or conditional cooperators. Second normative behavior and social approval may be an important aspect of behavior and may explain high degree of cooperation. We model these features by supposing that cooperative behavior is an implicit norm from which an idiosyncratic cost (emotions) is triggered. With global interaction two types of equilibria appear : an equilibrium with defection and a polymorphic equilibrium in which cooperators and defectors may coexist under certain conditions on the distribution of emotions. Convergence to one or the other equilibrium depends on the initial proportion of cooperators. We show that such a conclusion depends on the type of interaction : local versus random. With small sample sized local interaction cooperation is resilient with the by-side effect that cooperative zones appears. This imply that individuals are more frustrated in a local interaction situation where frustration is an indicator of their willingness to cooperate given the population rate of cooperation but their impossibility to do so given their environment. Moreover, cooperators' fitness is higher than defectors' fitness with local small interaction whereas the opposite is true in other cases.

Key-Words : Interaction structure, segregation , cooperation .

1 Introduction

One question in the social sciences has been to explain the observation of large difference in outcomes in the absence of commensurate difference in fundamentals. We show that segregation where segregation stands for zones of cooperation versus non cooperation can appear in the context of social dilemmas. This is an important issue since social interactions may be constrained by individuals' localisation. For example, residential segregation has been extensively studied in the context of racial segregation [14] with the implication that ghettos formation may give rise to by-side effects of high criminality and non cooperative zones. This paper shows that a factor explaining

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cooperative segregation stems from too narrow local interaction opportunities between individuals. The implication is that people feel more frustrated in such a context as some of them would like to cooperate given the overall cooperation rate but cannot due to bad neighbourhood and a lack of mobility. This contrasts from the case where people may interact with a sufficiently large sample of individuals. In the latter, convergence is obtained to a high or low level equilibrium with no segregation and frustration similar to the equilibrium of global interaction where convergence to one or other depends on the initial proportion of cooperators.
The modelling is an extended prisoner's dilemma where we integrate two features concerning individual rationality related to observations in experimental economics. A common conclusion in the experimental literature on prisoner's dilemma and public good games is that individuals have different behavior underlying a vast diversity in preferences and the existence of reciprocity type interactions ([11], [3]) leading to conditional cooperation in public good games [6].

Moreover, globally individuals adhere to cooperative norms both in repeated and non repeated interactions although this may depend in a non trivial way on the type of social groups ([8] , [9]) and differ across individuals within a group ([4]). Individual modelling in this paper use these facts and consider that people have *prosocial emotion* (Bowles and Gintis [2]) albeit at a different degree. According to Bowles and Gintis, "belongs to prosocial emotions : shame , guilt , empathy, and remorse all of which involves feeling or discomfort at doing something that appears wrong according to one's own value and or those of other agents whose opinions one values". Prosocial emotions work like an internal self-punishment when people deviate from the social norm. Social norms may lead individuals to behave differently in the same objective situation depending on how strongly they value conformance with (or deviance from) a norm (Olstrom [12]). Prosocial emotions could be a measure of conformance to the norm. A norm may result in some majority behavior if people follow the norm. In turn, individuals' expectations will be shaped by the observation of others' behavior and reinforce the norm if the norm is a best response given this expectation (including probably non tangibles like pro-social emotions in the payoff matrix). This is typical for coordination games and in this case the norm resumes one of the two equilibria called a convention [15], [16]. With best reply players, convergence to one or the other convention will be history dependant or to the risk dominant equilibrium in stochastic games [16]. If the norm is not an equilibrium of the basic game, as for example cooperative behavior in social dilemmas, then compelling to the norm is generally enforced by some regulatory mechanism, external (sanctions) and/or internal (conformity principle). Such regulatory mechanism must transform the payoffs so that the new structure allows the norm to be a best response for most people except probably for some of them.

We adopt this point of view when modelling a social dilemma in this paper. There may be a sense in which people adhere to the cooperative norm although this is not an equilibrium in a prisoner's dilemma. Social approval or disapproval may function as a punishment device for people when deviating from the cooperative norm [5]. In the transformed game including emotion cooperation may be a best response for some people given the overall cooperating rate and their emotional value to conformance with the norm. Nevertheless, for a punishment mechanism to be effective it must be that deviation from the norm is observed by some people. Experimental economics has also shown that pro-social behavior is affected by anonymity in action or privacy. One can suppose that a higher distribution of emotional costs within the group is obtained when the behavior is more observable by the group members (*i.e.* less privacy and anonymity) or if there is a lower social distance among the group members. In this paper we treat the distribution of emotional costs in the society as given and study the effect of interaction on the emergence of patterns.

Section 2 presents the extended prisoner's dilemma with emotions. We deduce the bayesian equilibrium in a two player game where emotions correspond to the type of player. The equilibrium with cooperative behavior depends on the distribution of emotional costs of players. In a population game interpretation with global interaction, the equilibrium structure of the population can be "polymorphic" (e.g. with coexistence of cooperators and defectors) . Players with high emotional costs cooperate while those with low emotional costs defect resulting in a proportion of cooperators and defectors which generates these behavior. Section 3 presents the simulation model where interactions may be local or random with different sample size. For each type of structure of interaction we show the results obtained for cooperation level, segregation and frustration (unhappiness). We compare each type of interaction among them and with the expected global equilibrium.

2 A social game with conditional cooperation

An emotional game

Our modelling uses two facts : first in many situation people know which is the right action to follow either by cultural or legal prescriptions or by individual learning. Second an individual deviating from a norm suffers from shame which is an idiosyncratic emotion. Our aim is at modelling a situation where social cooperation may be sustained by pro-social behavior (social disagreement and blaming, pairs punishments,...). In the following we interpret the cost of deviation from a social norm as a emotion and model a social dilemma by a prisoner's dilemma with an emotional cost from deviating from cooperation which represents then the norm on which player should agree on. More specifically, there is a population of N agents i ($1 \leq i \leq N$) who play the following game. In each period, two randomly chosen individuals from a large population are matched together to play the following game :

		Player 2	
		$s^2 = 1$	$s^2 = 0$
Player 1	$s^1 = 1$	$G - C$	$-C$
	$s^1 = 0$	$G - X^i$	0

Table 1: Payoff matrix

Each individual has a private gain $G > 0$ if the other individual cooperates. The cooperating costs is C with $0 < C < G$ and benefits only to the other individual. Cooperation is costly for the individual although beneficial for the other individual. Each agent has a type X^i which is private information to him and represents a cost of deviating from cooperation. Each X^i is drawn independently from an identical, continuous and strictly increasing probability distribution $F(x)$ on $[0, X_M]$ which is common knowledge [1] . A free rider ($s^i = 0$) does not support this cost but supports its emotional cost X^i whenever faced with a cooperator. A pure strategy for an agent is a function $s(X^i)$ from $[0, X_M]$ into $S^i = \{0, 1\}$. Let η_c be the probability that an individual cooperates. The utility function of individual i can be written as :

$$u^i(s^i, s^j) = s^i \left[-C + X^i s^j\right] + s^j \left[G - X^i\right] \tag{1}$$

Equilibrium analysis

An emotional game Γ^b is a Bayesian game

$$\Gamma^b = (N, (S^i)_{i \in N}, (X^i)_{i \in N}, F, (u^i)_{i \in N}, (\zeta^i)_{i \in N})$$

where agents' type correspond to their emotional cost and with a specified prescribed profile of actions (the norm) $\zeta^i)_{i \in N}$ from which emotions are triggered. N is the set of players, $(X^i)_{i \in N}$ a set of possible types given by players' emotional costs, F the exante cumulative probability distribution over the profile of players' types which is common knowledge among the players, $(S^i)_{i \in N}$ a set of actions and $(\zeta^i) \in (S^i)$ the prescribed profile of actions for each i. As usual Γ^b is common knowledge among players. In general, the prescribed action may be seen as a way a player should play the game (the definition of a norm by Homans [10]) and cultural, social or legal factors may determine such a profile or it may simply be learned by the player during the game. For an emotional game, a player has an emotion from deviating from his prescribed action. In our case, the reference action (i.e. the implicit norm) is cooperation. More generally , the implicit norm of each player should be some profile of actions which is seen to be relevant and beneficial for the group. Let η^j be the probability that $s^j = 1$. Let $X_c = C/\eta^j$. A player i's best response $\eta^i(X)$ depends on X_c :

$$\text{if } X^i < X_c \Rightarrow \eta^i = 0 \tag{2a}$$

$$\text{if } X^i = X_c \Rightarrow \eta^i \in [0, 1] \tag{2b}$$

$$\text{if } X^i > X_c \Rightarrow \eta^i = 1 \tag{2c}$$

Definition 1 *A Bayesian equilibrium is a pair of strategies* $\left(s^{i^*}(.), s^{j^*}(.)\right)$ *such that for each player i and every possible value* X^i *, strategy* $s^{i^*}(X^i)$ *maximizes* $Eu^i(s^i,$ $s^{j^*}(X^j)|X^i)$.

Let $G(X) = 1 - F(X)$. We have the following characterization of a Bayesian Nash equilibrium :

Theorem 2 *Bayesian Nash equilibria are given by*

$$\eta^* = 0 \tag{3a}$$

$$\eta^* = G\left(C/(\eta^* X_M)\right) \tag{3b}$$

1. The game with no emotional cost is a prisoner's dilemma.

Proof : see Phan-Waldeck.

Note that there is a necessary condition for the existence of an equilibrium with cooperation that is $C < X_M$ since $X^i \in [0, X_M]$ must be greater than X_c. We can also interpret this game as a population game with utility function defined in equation 1. With a proportion η of cooperators the average utility of individual i playing against the field is :

$$u^i(s^i, \eta | X^i) = G\eta - X^i(1 - s^i)\eta - s^i C \tag{4}$$

For a large population, depending on the parameters $C, F(.)$ a polymorphic equilibrium exists with coexistence of cooperators and free riders given by equation 3b ((Gordon *et al.* [7]). The next section contains simulation results of a local interaction model with stochastic best response learning. In doing simulations, individual emotions are a N-sample from a uniform distribution on $[0, 1]$. Defining $c = C/X_M$, the equilibrium configuration for a uniform distribution with cooperation is given by

$$\eta^* = (1 - \frac{c}{\eta^*}) \tag{5}$$

and has two fixed points given by

$$\eta^* = \frac{1 \pm \sqrt{\Delta}}{2} \tag{6}$$

with $\Delta = 1 - 4c$ given that $c \leqslant 1/4$. The only stable equilibrium corresponds to $\eta^* = \dfrac{1 + \sqrt{\Delta}}{2}$ with a basin of attraction given by $\eta > \dfrac{1 - \sqrt{\Delta}}{2}$. This corresponds to the global interaction prediction with high level of cooperation , the other equilibrium being with full defection.

3 Local interaction model

Simulation settings with local interactions and some results

There may be many possible types of interaction : global versus local, random versus fixed. We are interested in the study of patterns of cooperation and segregation when interaction is among a small number of agents in comparison with global interaction predictions. At each period a random sample of n agents play the social game. Each of them, say i, independently draw a sample of k other players and choose a stochastic best response to η^i_k where η^i_k is the proportion of players playing $s_1 = 1$ in the sample of player i : the strategy is randomly chosen with a probability ϵ and a best response to the proportion η^i_k with a probability $1 - \epsilon$. The neighbourhood is either local (k nearest neighbour on the lattice) or random. For the simulations, the sample size of neighbourhood will be taken to be one of $k = 4, 8, 24, 44$ from a population of $N = 100$.

In this section we present simulation results with the following parameters setting : $X_M = 1$, $C = 0.2$, $G = 1$. For these parameters, the equilibrium under global interaction (assuming a uniform distribution on $[0, 1]$) depends on the initial proportion of cooperators. With less than 27.6% of cooperators convergence is to pure defection ;

otherwise an equilibrium with 72.4% of cooperators is expected. At time t, we define the state of the system has $s(t)$ by a N-tuple $\left(s^1(t), s^2(t), ..., s^N(t)\right) \in S^N = \{0,1\}^N$.

Figures 1, 2 and 3 show three snapshots representing the state space of cooperators and defectors after 3000 time periods with three different initial settings : a weak initial proportion of cooperation of 25% and mean emotion 51.4 (figure 1), a weak initial proportion of cooperation of 20% and emotion 50.16 (figure 2) and a large initial cooperation of 65% and mean emotion of 51.4. Note that since mean emotion in figures do not correspond exactly to 50 from a uniform distribution on $[0, 100]$, the bifurcation point of 27% is not exact and a mean emotion greater than 50 could be favour the high proportion equilibrium in case 1. Indeed cooperation appears for a sufficiently large sample size ($k = 44$) and random interaction which may have appeared by favorable random agent matching. And since sampling is large ($k = 44$) such a cooperative pattern will persist. The local counterpart does not show the emergence of cooperative zones.

When the sample size is equal to 4, some cooperation is obtained in all 3 figures although for the figure 2 , this was unexpected from global equilibrium analysis. Moreover when initial cooperation is high (equal to 65% in figure 3), high cooperation is attained but the configuration with local interaction and sample size 4 where the final state shows less cooperators. This will be a general result shown in the following : local interaction with small sample size produces in general cooperative zones although when cooperation is predicted in a global equilibrium, the cooperation level will be lower than for other configurations of sampling. It also implies that frustration and segregation is more probable in this case. When sample size increases to 8 some cooperative zones persist only when cooperation is local. This shows that localized interaction in small groups may are a factor which may explain segregation.

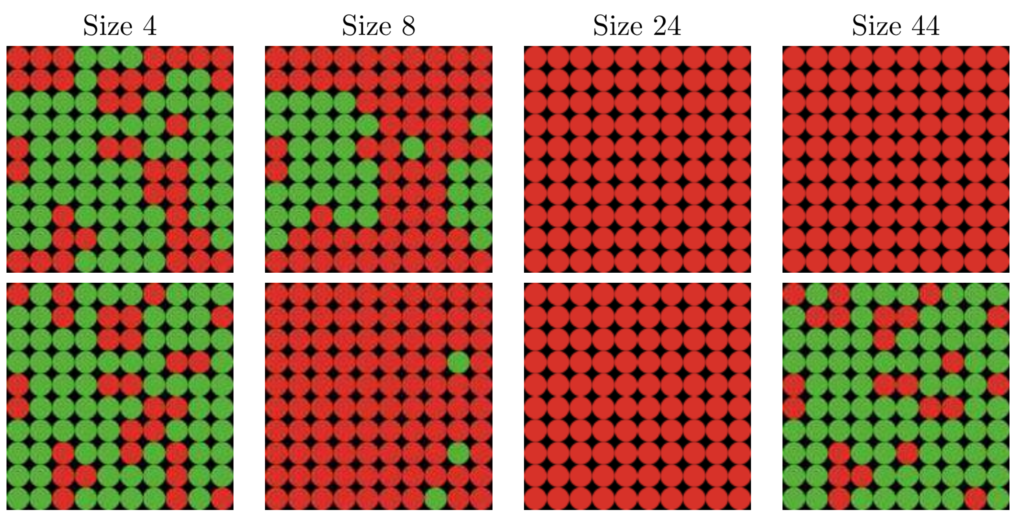

FIGURE 1: Initial cooperation 25, Mean emotion 51.4. Top panels : local interactions. Bottom panels : random interaction. Theoretical model bifurcation at 27.64% , mean emotion 50, equilibrium 0 or 72.

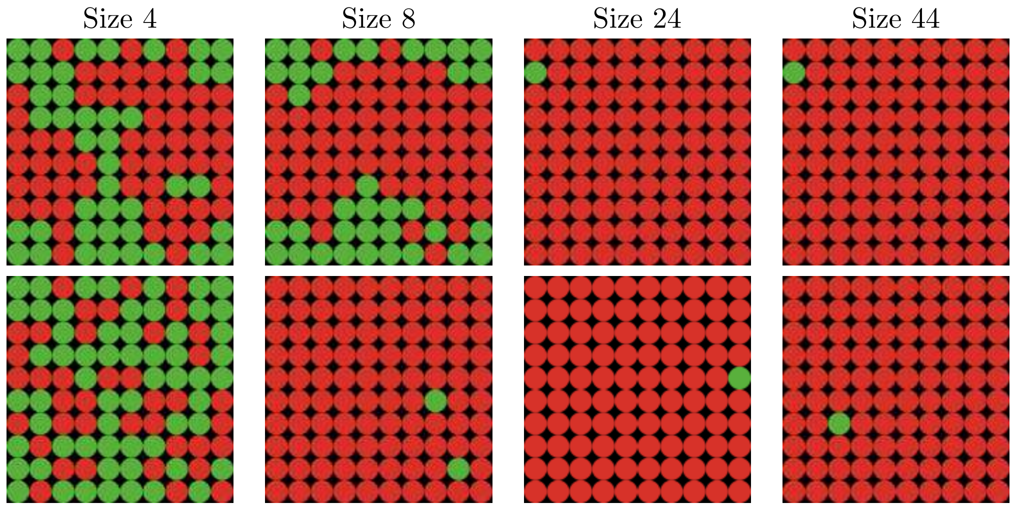

FIGURE 2: Initial cooperation 20, Mean emotion 50.16. Top panels : local interactions. Bottom panels : random interaction. Theoretical model bifurcation at 27.64% , mean emotion 50, equilibrium 0 or 72.

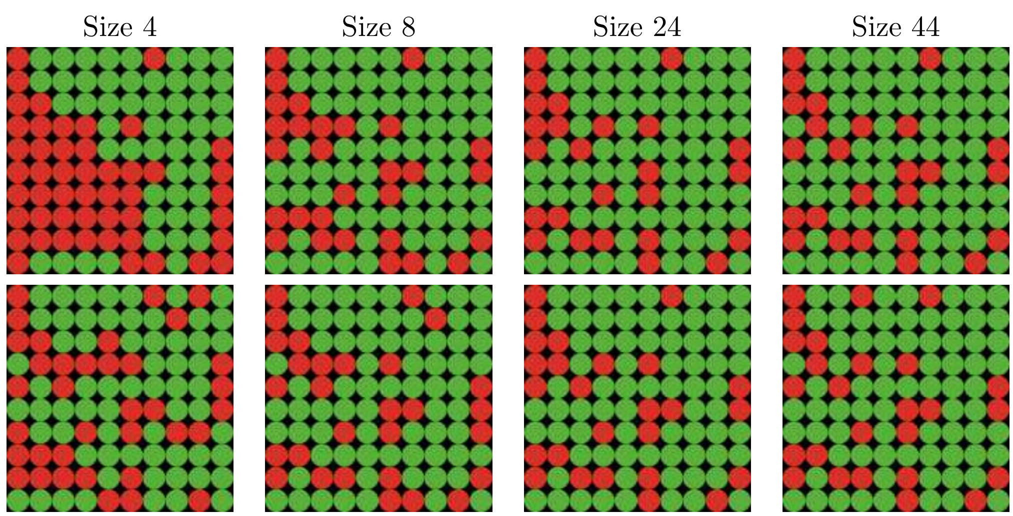

FIGURE 3: Initial cooperation 65, Mean emotion 51.4 . Top panels : local interactions. Bottom panels : random interaction. Theoretical model bifurcation at 27.64% , mean emotion 50, equilibrium 0 or 72.

Simulation results : generalization

Table 2 in the Appendix show data from 33 runs with the following parameters configurations : at each time period t, $n = 5$ randomly chosen players choose a stochastic best response ($\epsilon = 2\%$) to a sample from the the state space $S^N(t-1)$; total number of periods is $T = 3000$. In the table, each line (seed) corresponds to the same initial configuration. That is, each line corresponds to the same initial parameter configuration concerning initial cooperation and sample distribution of emotions. For each seed, 6 runs using different localized interaction structure were performed. These are L4, L8, L24 , R4 , R8, R24 corresponding to local (L) versus random (R) interaction for different sample size levels $k = 4, 8, 24$. This allows a cross comparison of interaction procedure independently of initial settings.

The 15 initial lines (seeds 50 to 110) where favourable to the equilibrium with full defection although for seed 35 and 110, this conclusion was particularly unsure because initial cooperation was near the theoretical bifurcation level and mean emotion above the theoretical 50 level. Lines with seed 25 to 15 contain runs for which global interaction would predict the high level equilibrium although for seeds 70 , 90 and 60, this prediction was particularly unsure. First, mean emotion was low which may imply non existence of a high level equilibrium (see equation 6) and second for seed 25, the combination of low initial cooperation 29% and low mean emotion 46.9 renders the theoretical and from the simulation bifurcation point quite close together [2]. In the following we will perform some non parametric tests on a restricted parameter configuration set where we eliminated the above seeds and called the new set, the restricted parameter configuration set adjusted for critical seeds. For this set, global equilibrium prediction were more reliable.

Figure 4 shows that cooperation is higher and less dispersed with local interaction and small sample size (4 and 8) than with other sampling configurations. The right hand side figure represents the same information with respect to mean and standard deviation. For local interaction with 4 neighbours (L4), and to a lesser degree L8, the impact of the initial configuration (initial number of cooperator and mean emotion in the population) seems less important than for other configurations which show more dispersion in cooperation. This is also seen in figure 5 where we plot cooperation in function of initial mean emotion (left plot) and initial cooperation (right plot). Remember that the equilibrium configuration has two equilibria one with full defection and one with a cooperation level of 72%. The theoretical bifurcation point is at 27.64% with a perfect uniform distribution. In Phan and Waldeck [13], we showed that a first order dominance on the distribution of emotional cost would lead to a higher degree of cooperation (with a decrease in the bifurcation point). If the increase in mean emotion would be due to an increase in first order stochastic dominance, we could thus expect an increase in cooperation both due to an increase of the proportion of cooperators at the high equilibrium and an increase in the basin of attraction. *Cetirus paribus* a

2. To compute the bifurcation point for the simulation one should have access to the distribution of emotions. This is cumbersome and a first approximation still using the uniform distribution assumption would be to take $X_M = 2*$ mean emotion.

higher mean emotion should not lower the degree of cooperation. Moreover we expect that with a higher initial cooperation level, final cooperation should not be lower.
We performed the following linear regression analysis : COOP $\sim Du.L8 + Du.L24 + Du.R4 + Du.R8 + Du.R24+$ Initial.cooperation +mean.emotion where $Du.$ stand for the dummy variable (equal to 1 for the corresponding interaction category and 0 otherwise). Results in table 3 show that mean emotion and initial cooperation are highly significant in explaining cooperation. Moreover, the average cooperation level is statistically higher with local interaction with sample size 4 (L4) than with any other type of interaction with exception for interaction type L8. Small local interaction seems to preserve cooperation. Looking at figure 5, for local interaction with sample size 4 and 8, and random interaction with size 4, mean emotions seems to be a major factor affecting the degree of cooperation with an almost smooth linear relationship between both variables for local interaction. A linear regression shows indeed that **initial cooperation** is not significant at any level of significance both for L4 and R4 and highly significant for mean emotion (tables 4 and 5). For L8 (not shown) both parameters are highly significant. We performed regression for other interaction type model which showed that initial cooperation and mean emotion where always significantly different from zero at least at a 5% level.

To go a step further into the analysis of data, we checked whether starting from an initial basin of attraction favourable to one of the two equilibria we stayed in the basin of attraction by period 3000 (Tables 6 and 7). For this, we performed a Chi-2 test on the restricted parameter configuration set (seeds 105 , 130, 250, 160, 150, 95, 260, 0, 300, 10, 220, 40, 110) (see table 10). For these seeds, starting with an initial cooperation level of less than 27 we should expect an equilibrium of full defection to appear. In this case, we should have the 13 configuration ending up with a value of less than 27. To perform the chi test we added a configuration (seed 75) for which a high cooperation equilibrium was expected. The expected final configuration for the chi-test was 13 low and 1 high cooperation level configurations under H0. The result was that L4, L8 and R4 could be rejected (p-value < 0.0001) (Table 6). For other configurations, especially R24 and L24, the level of cooperation was near to zero in all cases which given the stochastic best response indicates convergence to the low equilibrium. The same procedure was applied to the simulations favorable to the high equilibrium (seeds 20, 45, 55, 85, 5, 65, 100, 120, 30, 115, 75, 80, 15) (see table 8). To perform the Chi-test, we added seed 50 (low equilibrium expected) to the cases in the restricted set which should predict the high equilibrium. The anticipated final configuration was 1 low and 13 high cooperation level cases under H0. We considered that high equilibrium was attained when final cooperation level after 3000 periods stayed in the basin of attraction of the equilibrium (i.e. was greater than 27). configuration R4, H0 (convergence to high equilibrium) was rejected for R4 (p-value $= 0.000$) and R8 (p-value$= 0.038$).

Since apart from R4 (and slightly R8), we could not reject H0, what is the configuration which best converges to the high equilibrium ? The highest mean was attained for configuration R24 (69%) followed by L24 (62%) and R8 (59%)(table 7). R24 and L24 showed also the most regular high level of cooperation (lowest standard deviation) as did L4 but at a lower level of cooperation. The standard deviations of L4 and R24 were the lowest. In contrast R4 and R8 have the highest dispersion in outcome (highest standard deviation) showing prediction of high equilibrium could not be trusted (as already shown by the CHI test).

Table 9 cheked whether we could consider than we have equality of mean in cooperation between different type of interactions when high equilibrium was predicted. Indeed R24 configuration had the highest level of cooperation with R8. R8 act as an intermediary figure for cooperation as it shows no significant difference in means with configurations L4, L8, L24. However, figures for R8 were much more dispersed than for the later figures. It is difficult to conclude from the the wilcoxon analysis since it is only a partial ordering analysis and no transitivity is assured at a global level. From the means, we have $R4 < L4 < L8 < R8 < L24 < R24$). In comparing only local interactions, one conclusion is that $L4 < L8 < L24$ with significant level $**$ between 0.001 and 0.01 for each inequality. Larger sampling favors higher level of cooperation. A weaker conclusion hold for random sampling since we can only conclude that $R4 < R8$ and $R4 < R8$ at significant level $**$.
Table 6 shows the figures when low equilibrium is expected. Table 11 cheked whether we could consider than we have equality of mean in cooperation between different type of interactions when the low equilibrium is predicted. One conclusion is that two groups exists : one where the low equilibrium is not attained (R4, L4, L8) for which there is no significant difference in mean cooperation among the members of the group and one with low cooperation which is significantly different from the primer group and is composed of R24, L24, R8. L24 and R 24 perform equally well and R8 average cooperation is equal to R24 one with a significance level p-value of 0.08.

Segregation

If we want to measure segregation between cooperators and defectors, we have to define a normalized index of segregation taking into account for the fact that the proportion of cooperators varies during a run. We do that in the spirit of Carrington and Troske. A natural measure of segregation would be a function τ defined as the sum over all agents of the number of red-green pairs in a local neighbourhood of sample size k. The higher this index the lower segregation. Since k and η vary accross and within a simulation, we need to define a unit free measure of segregation. Segregation arising by randomness with same parameter should not be consider as real segregation. A random configuration with parameters k, η_c, N and population size N would give a expected value of $\hat{\tau} = k * \eta_c * (1 - \eta_c) * n^2$ of segregation so that a normalized degree of segregation is $\tau_{norm} = \frac{\hat{\tau} - \tau}{\hat{\tau}}$ (see [1]). If τ_{norm} is near zero then segregation is not different from a random configuration. Higher values of τ_{norm} correspond to higher level of segregation.

Figure 6 shows a box plot of segregation versus type of interaction. Clearly local interaction leads to higher segregation both in the case of $k = 4, 8$. Remembering that these were also the cases where cooperation was mostly observed, we have the paradoxical effect that local interaction leads to robust cooperation with segregation. In fact it is segregation which supports localized cooperative interactions. In addition, we define an index of unhappiness as the proportion of people who would like to cooperate given their idiosyncratic emotion and overall cooperation rate. Unhapiness is linked to segregation and cooperation since local interaction lead to segregation and significant cooperation, some people will find themselves prisoner of zones of defection and be frustrated. The right figure 6 show that indeed dissatisfaction is the highest with L4 and L8. This shows that local interaction with small samples leads to situation where people may become frustrated in their environment. Ideally for these cases, after an initial rise in cooperation, interaction should become more random so that an equilibrium with a high level of cooperation could be attained. Figure 7 shows that cooperators are better off all than defectors with localized interaction. We computed the differential fitness between cooperators and defectors. Fitness was defined as "real" payoffs that is emotions where not considered. Fitness correspond thus to payoffs in a prisonner dilemma. Only for L4 and L8 are cooperators better off than defectors as shown in figures 7 . Another conclusion can be drawn from this result : if a reproduction process is introduced cooperators could survive and spread in a environment where interaction were localized. Overall mean fitness was higher in configuration L4 and L8 as shown in figure 8

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Appendix : tables and figures

Initial seed	mean emotion	Initial coop	Coop-L4	Coop-L8	Coop-L24	Coop-R4	Coop-R8	Coop-R24
50	47.6	4	38	1	1	3	0	1
105	49.1	6	42	1	1	1	3	2
130	51.4	6	37	11	1	44	3	1
250	55.1	10	68	73	2	69	0	0
160	45.7	11	24	6	1	3	1	0
150	52.0	11	45	55	0	2	1	0
95	48.8	12	39	24	2	11	0	0
260	52.0	17	58	0	1	3	79	1
0	56.5	17	79	83	0	81	0	1
300	50.2	20	42	35	1	60	2	1
10	48.6	22	39	24	0	35	0	0
220	53.5	22	70	69	2	75	2	1
40	47.8	23	44	8	1	4	0	0
35	52.7	25	63	76	78	72	79	78
110	50.9	27	51	56	0	64	0	1
25	46.9	29	50	1	0	3	1	2
20	52.1	35	61	70	78	73	80	76
70	41.9	37	13	2	0	2	1	0
45	50.7	41	48	48	66	36	68	72
55	44.9	55	40	39	40	3	4	62
85	48.7	60	44	47	56	6	60	67
5	51.4	65	51	71	75	64	71	74
65	46.0	70	32	35	37	3	0	58
100	48.9	72	43	54	58	7	58	60
120	52.0	72	53	61	66	62	68	72
30	48.9	74	55	65	66	1	57	69
115	48.1	84	49	46	52	6	74	71
75	51.3	88	58	77	75	66	81	77
60	42.7	92	23	23	0	0	0	1
90	43.4	94	33	16	2	1	0	3
80	50.6	98	56	66	72	7	74	69
15	51.1	98	39	65	71	62	69	69

TABLE 2: Data from simulations with different initial configuration (seeds) : mean emotion and initial cooperation

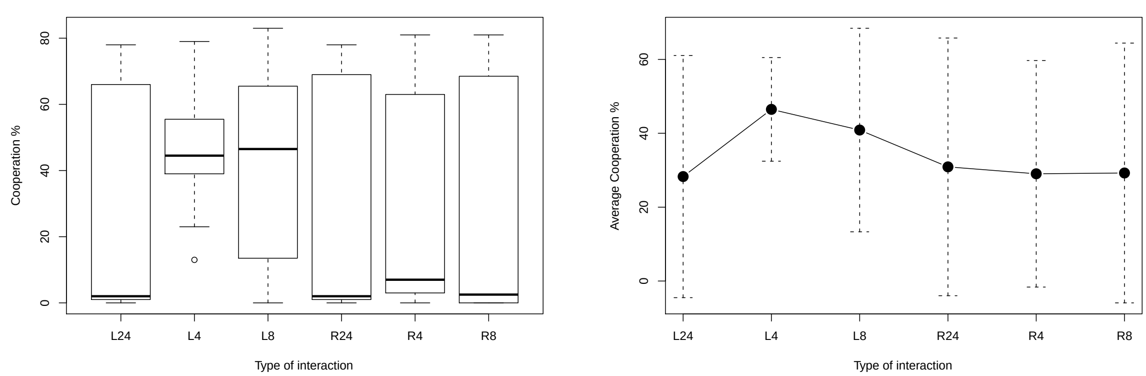

FIGURE 4: cooperation versus interaction type. The left plot represents the lower bound (whiskers line), 1st quartile (hinge), median, 3rd quartile (hinge) and upper bound (whiskers line) of the distribution of cooperation for each type of interaction. The Whisker lines indicates the smallest and largest observation falling within a distance of 1.5 the box size from the nearest hinge. Observations falling outside this range are considered extreme or unusual and are represented by a circle. Right plot : mean with standard deviation

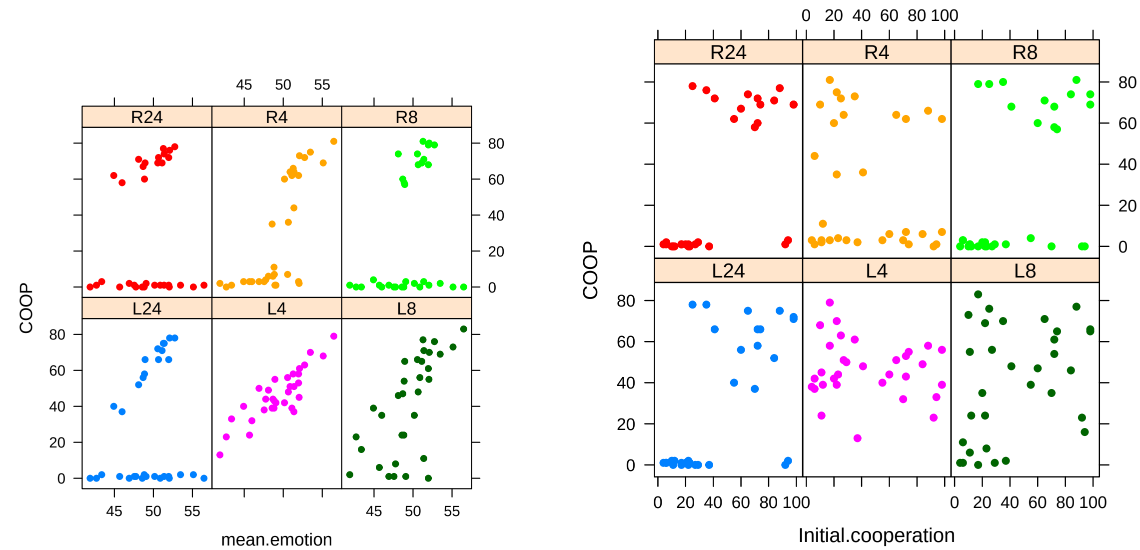

FIGURE 5: cooperation versus mean emotion (left plot) and initial cooperation (right plot)

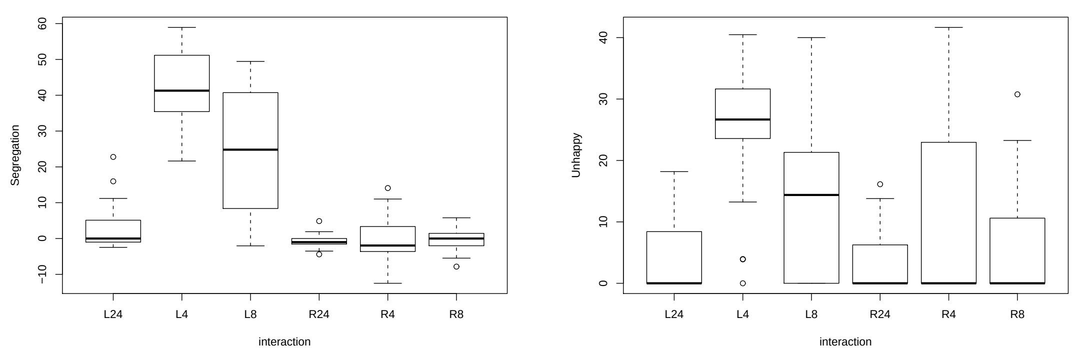

FIGURE 6: Segregation and unhappiness versus type of interaction

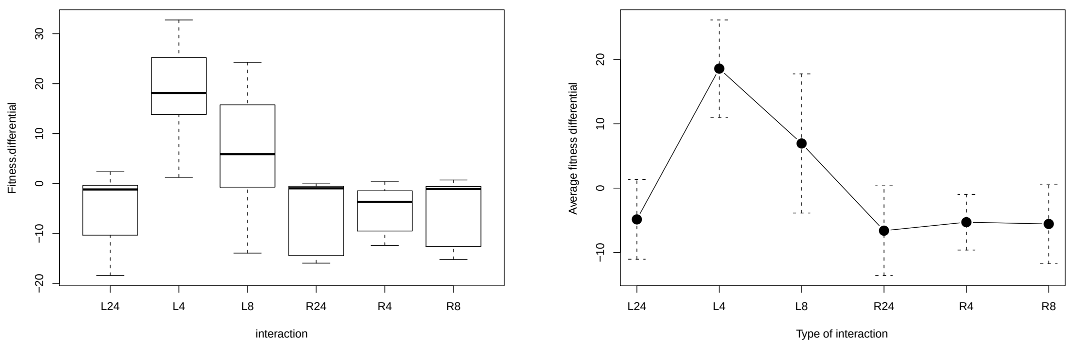

Figure 7: Fitness differential versus type of interaction

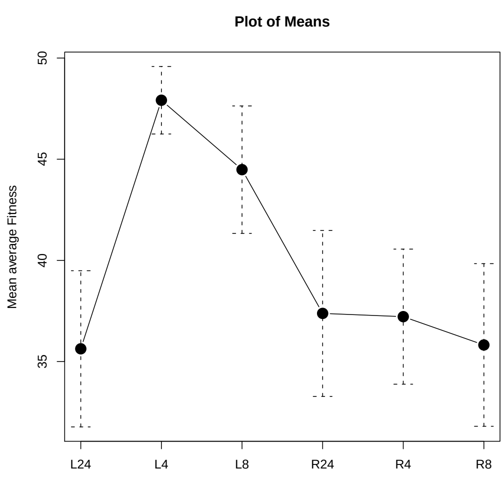

Figure 8: Average Fitness

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-226.8471	26.5415	-8.55	0.0000	$***$
Du.L8	-5.5937	5.7033	-0.98	0.3280	
Du.L24	-18.1875	5.7033	-3.19	0.0017	$**$
Du.R4	-17.4375	5.7033	-3.06	0.0026	$**$
Du.R8	-17.2187	5.7033	-3.02	0.0029	$**$
Du.R24	-15.5625	5.7033	-2.73	0.0070	$**$
Initial.cooperation	0.4945	0.0549	9.01	0.0000	$***$
mean.emotion	5.0946	0.5148	9.90	0.0000	$***$

TABLE 3: Regression : cooperation is the dependant variable. Independant variables are : initial cooperation, mean emotion and dummies for interaction type. Signif. codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 · 0.1. Residual standard error : 22.81 on 184 degrees of freedom ; Multiple R-squared : 0.4603, Adjusted R-squared : 0.4397 ; F-statistic : 22.42 on 7 and 184 DF ; p-value : ¡ 2.2e-16

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-140.46	20.00	-7.02	0.00	$***$
Initial.cooperation	0.06	0.04	1.47	0.15	
mean.emotion	3.73	0.39	9.52	0.00	$***$

TABLE 4: Regression for L4 : cooperation is the dependent variable. Independent variables are : initial cooperation, mean emotion

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-319.62	59.56	-5.37	0.00	$***$
Initial.cooperation	0.11	0.12	0.85	0.40	
mean.emotion	6.96	1.17	5.97	0.00	$***$

TABLE 5: Regression for R4 : cooperation is the dependent variable. Independent variables are : initial cooperation, mean emotion

	Coop-L4	Coop-L8	Coop-L24	Coop-R4	Coop-R8	Coop-R24	Equilibrium prediction
observed < 27	1	7	13	6	12	13	13
observed > 27	13	7	1	8	2	1	1
p-value	0.0000	0.0000	1.0000	0.0000	0.2994	1.0000	
	HO rejected	HO rejected	HO not rejected	HO rejected	HO not rejected	HO not rejected	

TABLE 6: H0 : Low equilibrium predicted

	Coop-L4	Coop-L8	Coop-L24	Coop-R4	Coop-R8	Coop-R24	Equilibrium prediction
observed < 27	0	1	1	8	3	1	1
observed > 27	14	13	13	6	11	13	13
p-value	0.2994	1.0000	1.0000	0.0000	0.0379	1.0000	
	HO not rejected	HO not rejected	HO not rejected	HO rejected	HO rejected (at 1%)	HO not rejected	

TABLE 7: H0 : High equilibrium predicted

seed	Coop-L4	Coop-L8	Coop-L24	Coop-R4	Coop-R8	Coop-R24
20	61	70	78	73	80	76
45	48	48	66	36	68	72
55	40	39	40	3	4	62
85	44	47	56	6	60	67
5	51.0	71.0	75.0	64.0	71.0	74.0
65	32	35	37	3	0	58
100	43.0	54.0	58.0	7.0	58.0	60.0
120	53.0	61.0	66.0	62.0	68.0	72.0
30	55	65	66	1	57	69
115	49.0	46.0	52.0	6.0	74.0	71.0
75	58	77	75	66	81	77
80	56	66	72	7	74	69
15	39	65	71	62	69	69
Average	48	57	62	30	59	69
Median	49	61	66	7	68	69
Standard deviation	8.1	12.7	12.7	28.9	25.3	5.6

TABLE 8: Configuration with restricted seeds : HIGH equilibrium predicted.

p-value	Coop-L8-	Coop-L24-	Coop-R4-	Coop-R8-	Coop-R24-
Coop-L4-	0.006695**	0.002516**	0.05455 .	0.1619	0.001645 **
Coop-L8-		0.003655**	0.003718**	0.4317	0.002488**
Coop-L24-			0.001651**	0.8743	0.03241*
Coop-R4-				0.002623**	0.001656**
Coop-R8-					0.1803

TABLE 9: Wilcoxon ranked test : equality of means when HIGH equilibrium predicted.

seed	Coop-L4	Coop-L8	Coop-L24	Coop-R4	Coop-R8	Coop-R24
105	42.0	1.0	1.0	1.0	3.0	2.0
130	37.0	11.0	1.0	44.0	3.0	1.0
250	68.0	73.0	2.0	69.0	0.0	0.0
160	24.0	6.0	1.0	3.0	1.0	0.0
150	45.0	55.0	0.0	2.0	1.0	0.0
95	39	24	2	11	0	0
260	58.0	0.0	1.0	3.0	79.0	1.0
0	79	83	0	81	0	1
300	42.0	35.0	1.0	60.0	2.0	1.0
10	39	24	0	35	0	0
220	70.0	69.0	2.0	75.0	2.0	1.0
40	44	8	1	4	0	0
110	51.0	56.0	0.0	64.0	0.0	1.0
Average	49	38	1	35	7	1
Median	44	35	1	35	1	1
Standard deviation	14.9	28.0	0.7	30.7	20.8	0.6

TABLE 10: Configuration with restricted seeds : LOW equilibrium predicted.

p-value	Coop-L8-	Coop-L24-	Coop-R4-	Coop-R8-	Coop-R24-
Coop-L4-	0.03592*	0.001656**	0.1677	0.002066**	0.001656**
Coop-L8-		0.003264**	0.6947	0.02524*	0.003305**
Coop-L24-			0.002488**	0.5214	0.3046
Coop-R4-				0.03299*	0.002099**
Coop-R8-					0.08071 .

TABLE 11: Wilcoxon ranked test : equality of means when LOW equilibrium predicted.