

# Evolution of Cooperation and Discrimination in Software Development

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## **Abstract**

Software development projects typically involve repeated interactions among several groups of people. This setting seems well suited for an analysis by means of the standard-model of the evolution of cooperation, the Iterated Prisoner's Dilemma. Computer simulations of a population of stochastic reactive strategies show that the existence of intergroup discrimination can be modeled endogeneously as a result of noise due to misperception of the opponent's move.

## **1 Motivation**

Software projects typically consist of several steps with several partners cooperating to achieve a previously defined goal. In an ideal world a detailed project plan would be established early, and the final mile stone would be reached just as planned. However, real world requirements and resources are subject to change, and many unforeseen problems can occur; few large projects are finished on time, and the quality of the solution is often not satisfactory (Boehm 1991). Among the factors influencing software development risk are the dynamics of interaction among the project participants (Blokdiik 1987), especially when participants from different environments cooperate, such as in-house development and hired consultants. Misunderstandings due to differences in organizational culture are to be expected, as well as group selective behaviour (Janko and Mitlöhner 1999).

We model group selective behaviour by means of computer simulation of repeated interactions. Intergroup discrimination can be modeled endogeneously as a result of noise due to misperception of the partner's action. We argue that a cooperative outcome is consistent with even a high amount of initial group selective propensity but not with even a moderate amount of noise due to misperception.

Limiting the analysis to projects with two participating individuals or teams we model the interactions as a 2-person game with the strategies cooperate (C) and defect (D). The following payoff matrix defines the utilities for the row and column players depending on their strategy choices:

	C	D
C	(R,R)	(S,T)
D	(T,S)	(P,P)

The prisoner's dilemma is realized with  $T > R > P > S$ : both partners opting for Defect results in the low payoff  $(P, P)$ , while both partners choosing Cooperate returns in the higher payoff  $(R, R)$ . However, the highest payoff  $T$  can be realized by defecting on a cooperating partner, who in turn receives the lowest payoff  $S$ . An example in terms of negative utilities can be formulated using costs associated with information exchange: by choosing to cooperate and expending documentation costs  $d$  team A can document their part of the system sufficiently so that team B can readily use team A's modules; if team A plays Defect then this documentation is lacking, and team B has to expend higher costs  $e$  to derive the necessary information. The payoffs in terms of negative utility are  $R = -d, P = -e, T = 0, S = -d - e$ . With  $e > d$  the payoffs of the prisoner's dilemma are realized.

For a fixed number of iterations which is known in advance to the players the dominant strategy is Defect since it maximizes minimal payoff for each player. However, in an iterated prisoner's dilemma where the number of iterations is not initially known to the players cooperative outcomes are possible (Axelrod 1984). Information technology projects typically involve repeated interactions of the participants. Due to changes of schedule and other factors the number of interactions is not known initially. Therefore, the iterated prisoner's dilemma is a plausible model of the development process.

In an iterated game cooperative and non-cooperative behaviour will typically be reciprocated to a certain extend. The players are influenced in their choice of strategy by the opponent's previous move. Such reactive strategies in the iterated prisoner's dilemma can be modelled stochastically.

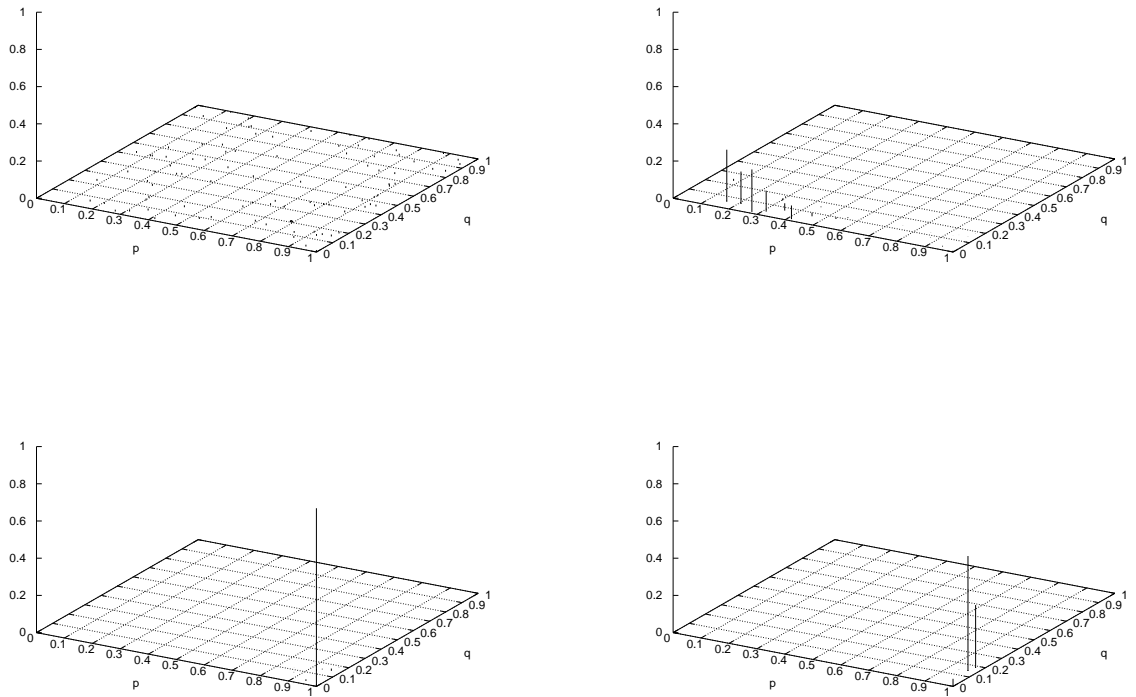


Figure 1: Evolution of cooperation in stochastic reactive strategies: initially (upper left plot) all 100 strategies are present with equal frequencies. After 100 time steps (upper right) the non-cooperative strategies which almost always defect dominate the population. After 350 time steps (lower left) the Tit-for-Tat strategy has taken over the population. After 500 time steps (lower right) the generous TFT strategies prevail.

## 2 The Evolution of Cooperation

A stochastic reactive strategy specifies the conditional probabilities of C and D as a reaction to all possible histories of the game that fall into the memory of the player. In the simplest case, where the initial probability to play C in the first round can be ignored due to the infinite iteration of the game and the memory of the players is shortest, taking account only of the opponent's move in the previous round, a reactive strategy  $E$  can be determined by the pair  $(p, q)$ , where  $p$  is the conditional probability to play C after an opponent's C in the previous round, and  $q$  is the probability to play C after an opponent's D. Tit for Tat can be represented by the pair  $(1, 0)$ , generous TFT by  $(1, 0.3)$ , the random strategy by  $(0.5, 0.5)$  and AlwaysD by  $(0, 0)$ .

For this case Nowak and Sigmund (1989) have shown that the payoff for a strategy  $E_i$  against a strategy  $E_j$  in the infinitely iterated prisoner's dilemma is obtained in terms of payoff notation as

$$A(E_i, E_j) = [(R - T) + (P - S)]cc' + (S - P)c + (T - P)c' + P \quad (1)$$

with

$$c = \frac{q_i + (p_i - q_i)q_j}{1 - (p_i - q_i)(p_j - q_j)} \quad \text{and} \quad c' = \frac{q_j + (p_j - q_j)q_i}{1 - (p_j - q_j)(p_i - q_i)} \quad (2)$$

Large organizations often employ a number of developer teams, and teams often participate in several projects. In order to model the evolution of strategies in a population of players we abstract from individual teams playing certain strategies and instead study the strategy population consisting of  $m$  stochastic reactive strategies  $E_i$ . The current state of the strategy population is denoted by the vector  $\mathbf{x}$  where  $x_i$  denotes the prevalence or frequency of strategy  $E_i$  in the population of players.

Applying the replicator equation which relates the growth in frequency of a strategy to its fitness Hofbauer and Sigmund (1988) have described the evolution of the reactive strategies for the infinitely iterated prisoner's dilemma as an adaptive dynamics, where the frequency of a reactive strategy in the following generation is given by

$$x_i(t + 1) = x_i(t)f_i(\mathbf{x})/\bar{f} \quad (3)$$

where  $f_i(\mathbf{x}) = \sum_{j=1}^m x_j A(E_i, E_j)$  denotes the average payoff for  $E_i$  in a population of strate-

gies with frequency-vector  $\mathbf{x} = (x_1, \dots, x_n)$  and  $\bar{f} = \sum_{i=1}^m x_i f_i(\mathbf{x})$  is the average payoff in the population.

Running computer simulations on the basis of this model Nowak and Sigmund (1992) have shown that cooperation can emerge among a population of randomly chosen reactive strategies, as long as a stochastic version of Tit for Tat is added to the population. In this setting it plays the role of a police for the enforcement of reciprocity, insofar as it is immune to exploitation and rewards cooperation. But since it is precisely this provocability that makes it susceptible to errors engendering an endless vendetta of retaliations, it is finally superseded by Generous Tit for Tat (a nice strategy that forgives every third defection).

The fact that the presence of Tit for Tat in the strategy population is necessary to bring about a cooperative outcome highlights the importance of a minimal social structure that is required for the evolution of cooperation. Even if Tit for Tat can be proven to be the strategy that can invade a population of universal defectors in the smallest cluster (Nowak and Sigmund 1990), its role shows that the prestructuring of the population determines the evolution of the patterns of interaction that constitute the final social structure.

The precise impact of the prestructuring of the population depends on the degree of its incorporation into the strategies: As Frank (1988) has shown, if cooperators can recognize each other with the help of some label they can increase their payoff by interacting selectively with one another. This mechanism can even explain the spontaneous emergence of label-selective behavior, as Rick Riolo quoted by Holland (1995) has shown with the help of computer simulations.

### 3 Cooperation and Discrimination

In interactions between partners of different origin such as in-house development versus cooperation with other organizations a certain level of discriminating behaviour is often observed in interactions with the alien group. In terms of reactive strategies the probabilities for Cooperate are group-selective, resulting in different  $(p, q)$  values for interactions among natives and between natives and aliens. In an extreme form cooperation only occurs among members of the same group.

We model discriminatory behavior by drawing inspiration from literature to construct group selective strategies  $E^J$  and  $E^H$  (for Jeckyll and Hyde) such that for each non-discriminatory strategy  $E^J$  with identical  $p_i$  and  $q_i$  values in all interactions  $E_i^J = ((p_i, q_i), (p_i, q_i))$  there is a

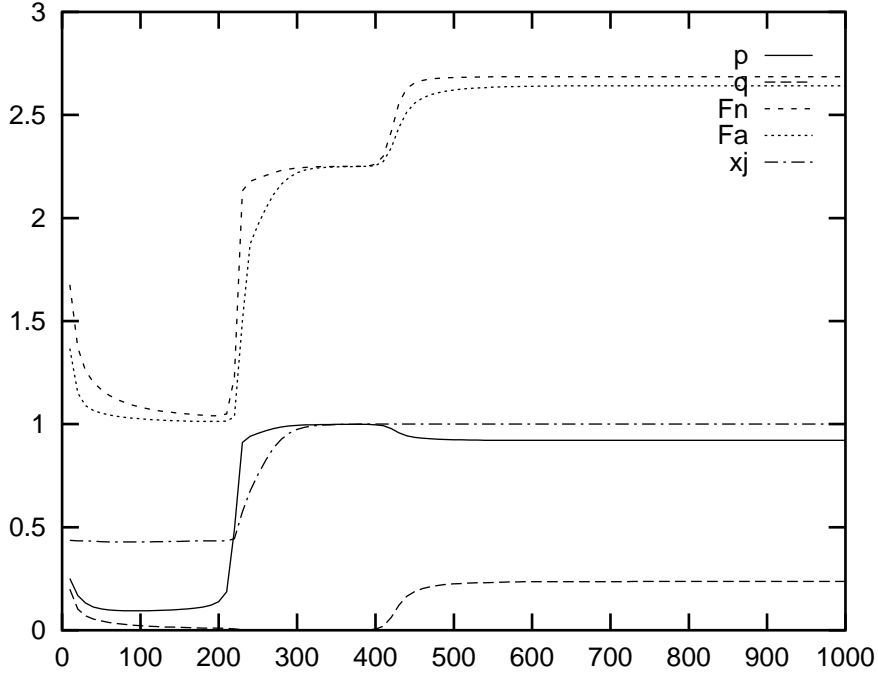


Figure 2: A non-discriminatory outcome is reached in spite of discriminatory strategies of 50% Hydes in the initial population.

corresponding Hyde strategy  $E_i^H = ((p_i, q_i), (0.001, 0.001))$  with  $p_i$  and  $q_i$  in case of interaction of players of the same origin and  $(0.001, 0.001)$  in case of interactions with players of different origin. The discriminating  $(p, q)$  values are not  $(0, 0)$  since in equation 2 we need  $p > 0$  and  $q > 0$ .

Each of these two subpopulations of strategies is characterized by a frequency vector consisting of the frequencies of the corresponding strategies and zeros otherwise such that  $\mathbf{x}^J + \mathbf{x}^H = \mathbf{x}$ .

The fitness  $f_i(\mathbf{x})$  of a given strategy  $i$  within a population of  $m$  strategies consists of the contributions of fitness it achieves when played by members of the own (native) group ( $f_i^n(\mathbf{x})$ ) and the alien group ( $f_i^a(\mathbf{x})$ ) weighted by their respective population shares  $r^n$  and  $r^a$ . The native or alien fitness of a strategy is the fitness this strategy achieves in the position of an alien or a native, respectively. As the interaction situations are defined by the groupwise pairings of the players the proportion of contacts of group  $x$  with group  $y$  is  $r^y$ . Therefore we get

$$f_i^n(\mathbf{x}) = \sum_{j=1}^m r^n x_j A(E_i, (p_j, q_j)) + r^a [x_j^J A(E_i, (p_j, q_j)) + x_j^H A(E_i, (0.001, 0.001))] \quad (4)$$

$$f_i^a(\mathbf{x}) = \sum_{j=1}^m r^a x_j A(E_i, (p_j, q_j)) + r^n [x_j^J A(E_i, (p_j, q_j)) + x_j^H A(E_i, (0.001, 0.001))] \quad (5)$$

$$f_i(\mathbf{x}) = r^n f_i^n(\mathbf{x}) + r^a f_i^a(\mathbf{x}) \quad (6)$$

If we denote by  $x_i^n$  and  $x_i^a$  the frequencies of strategy  $i$  in native and alien use, respectively, the frequencies in time step  $t + 1$  are given by

$$x_i^n(t + 1) = x_i^n(t) f_i^n(\mathbf{x}) / \bar{f}^n \quad (7)$$

$$x_i^a(t + 1) = x_i^a(t) f_i^a(\mathbf{x}) / \bar{f}^a \quad (8)$$

with the average native and alien fitness values

$$\bar{f}^n = \sum_{i=1}^n x_i^n f_i^n(\mathbf{x}) \quad (9)$$

$$\bar{f}^a = \sum_{i=1}^n x_i^a f_i^a(\mathbf{x}) \quad (10)$$

The total frequency of strategy  $i$  is

$$x_i(t + 1) = r^n x_i^n(t + 1) + r^a x_i^a(t + 1) \quad (11)$$

## 4 Simulations and the Impact of Perturbations

On the basis of this model, we ran simulations with different settings and random numbers to investigate the dynamic behaviour of the strategy population. We initialized the strategy population following Nowak and Sigmund (1992) with 100 pairs of  $p$ - and  $q$ -values distributed uniformly in the unit square; for each pair, we added a duplicate strategy: a Mr. Hyde lurking behind his Dr. Jekyll sibling and ready to defect in inter-group interaction. All 200 strategies have the same initial frequency of 0.005, allowing an equal proportion of Jekylls and Hydes. We ran 1000 time steps since preliminary tests showed in accordance with the results of Nowak and Sigmund that interesting dynamics occur only after the first several hundred time steps. We set

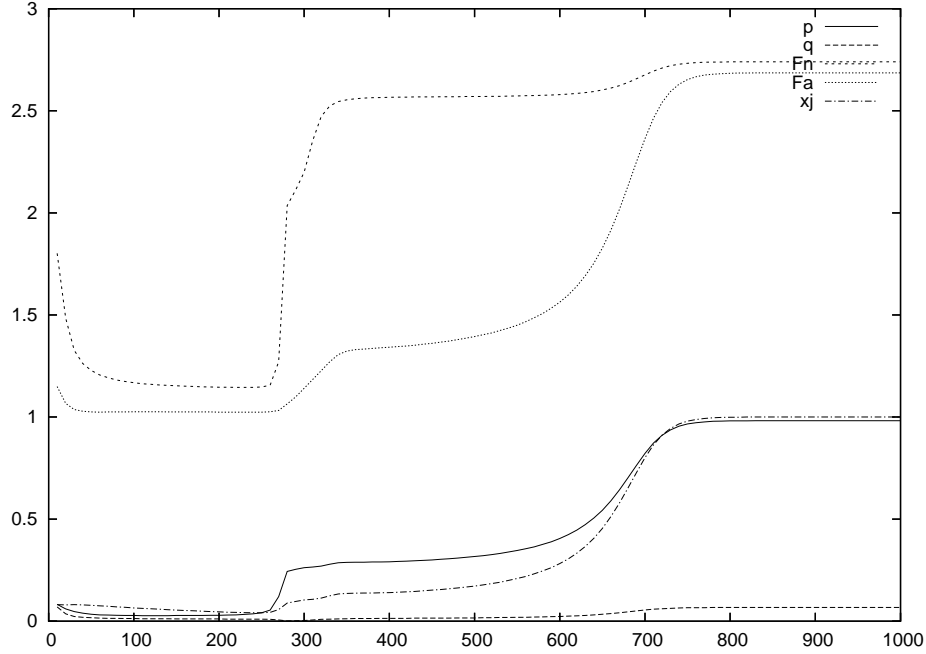


Figure 3: Even with a very high initial propensity to defect in inter-group interaction of 90% Hydes in the initial population a non-discriminatory outcome is reached eventually.

the proportion of aliens to 0.1. Figure 2 shows the result of a typical run.

In spite of the equal proportion of Hydes and Jekylls in the initial population, the outcome is largely cooperative and - above all - non-discriminatory (the Jekylls dominate the population). In this simulation, the shift towards a cooperative outcome occurs after time step 200: in accordance to Nowak and Sigmund, the  $p$ -value increases to one (the  $p$ -value of tit-for-tat), to be followed after time step 400 by the  $q$ -value, which rises to approximately 0.25, corresponding to a generous version of tit-for-tat (the weighted average  $p$ - and  $q$ -values were calculated as  $p = \sum_{i=1}^m x_i p_i$  and  $q = \sum_{i=1}^m x_i q_i$ ).

Most importantly for our concern with inter-group discrimination at time step 200 the proportion of Jekylls increases, taking over the population at time step 300. Parallely, the fitness for natives and aliens alike increases to approximately 2.6.

In figure 3 the initial proportion of Hyde strategies is set to 0.9, yet even with this very high initial propensity to defect in inter-group interactions a non-discriminatory outcome is reached eventually. This shows that the presence of discriminatory strategies in the initial population (even at a high proportion) alone is not sufficient to explain a discriminatory outcome.

Consequently, we have to look elsewhere for an explanatory variable for the presence and persistence of discrimination. The common cultural and normative background within an orga-



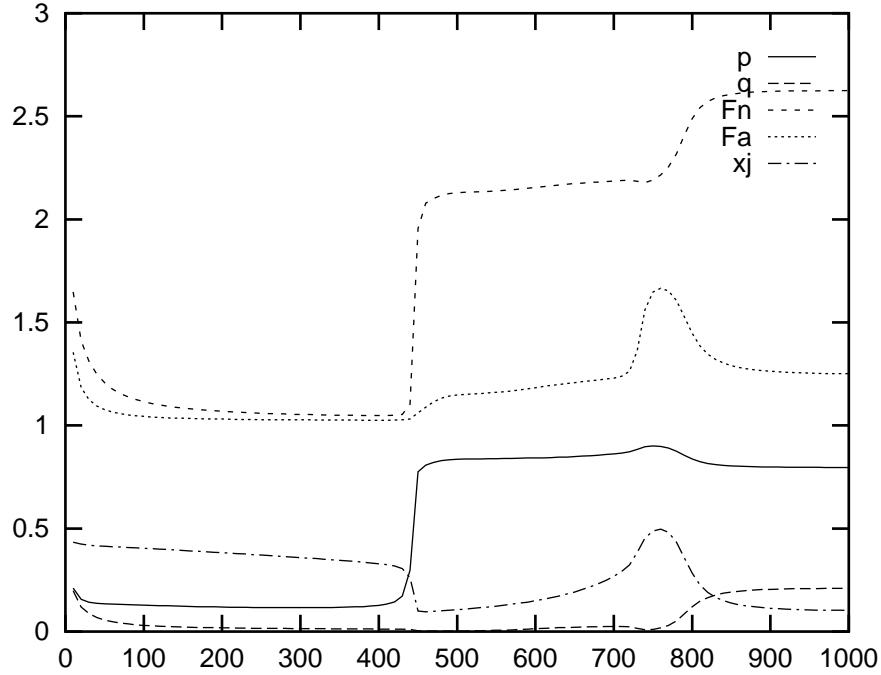


Figure 4: Discriminatory outcome in the presence of noise

nization can serve as the base for capturing uncertainty in social interaction. Introducing noise in the interaction models the danger of misinterpretation of the opponent's behavior and allows for some amount of misimplementation of the original strategies (Axelrod 1995).

We introduce noise due to misperception between groups with constant level  $\varepsilon$ : if a strategy of Jekyll type  $E_i^J$  has initial values  $(p_i, q_i)$ , then in inter-group interaction the probability  $\varepsilon$  of misinterpretation of opponent's move turns them into  $p'_i = (1-\varepsilon)p_i + \varepsilon q_i$  and  $q'_i = (1-\varepsilon)q_i + \varepsilon p_i$ .

The Hyde strategies remain unaffected by noise due to misperception because they are always defecting in inter-group interaction regardless of the opponent's move.

The Jekyll strategies are dramatically affected by such a setting, as illustrated in figure 4 plotting a representative run with a noise level of 0.05: note that the dramatic twist occurs after time step 400: the proportion of Jekylls decreases, resulting in a severe difference in fitness between natives and aliens. The aliens can finally achieve little more than the non-cooperative payoff. The increase of the  $p$ - and  $q$ -values characteristic for the basic model (see figure 2) is delayed by several hundred time steps, and the level finally achieved is lower, corresponding to a lower overall level of cooperation.

To evaluate the effect of noise, we ran the simulation for different noise levels from zero to 0.1, each time with 20 different random numbers. Figure 5 shows the average values for proportion of Jekylls ( $x_j$ ), overall fitness ( $F$ ), and fitness for natives and aliens ( $F_n$  and  $F_a$ , resp.) at the

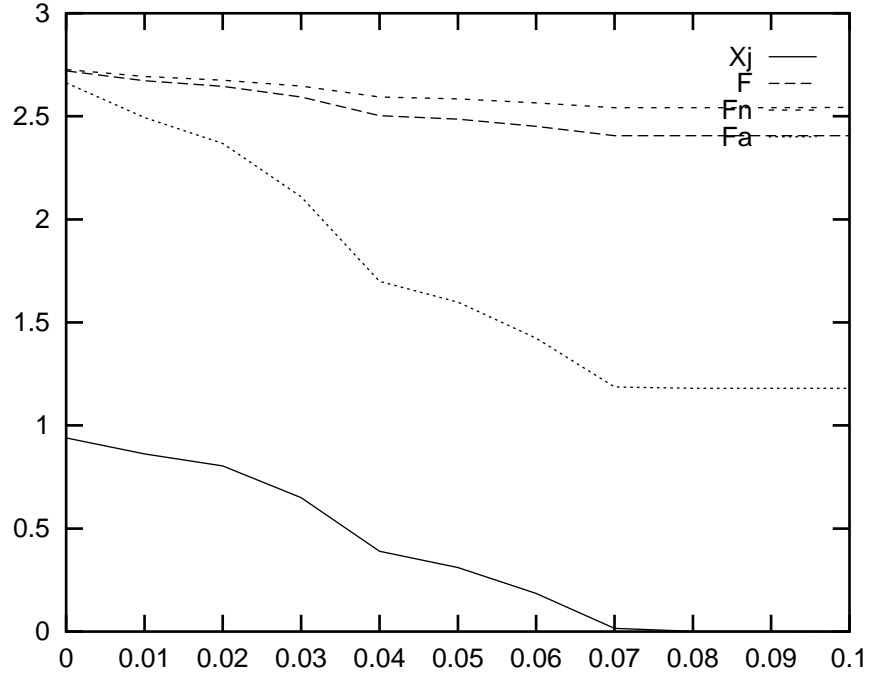


Figure 5: Influence of different noise levels on the outcome

final time step 1000. The proportion of Jekylls drops with increasing noise; at a noise level of 0.07, it is almost zero.

The fitness conferred to natives remains almost unaffected by noise; the slight loss in overall fitness is due mainly to the severe loss in fitness for the aliens, which drops with increasing noise until the proportion of Jekylls has reached its minimum.

In figure 6, we plotted the fitnesses of the Jekyll and Hyde strategies for natives and aliens; native and alien Jekylls decrease simultaneously with increasing noise. The fitness of the native Hydes increases rapidly with noise, followed at a slower rate by the alien Hyde's fitness.

## 5 Conclusion

These results lead us to an ambivalent conclusion: on the one hand, we find a comforting relative robustness of the evolution of cooperation vis-a-vis discriminatory propensities in the initial strategy population: even if half of the strategies are of type Hyde, i. e. always defecting in inter-group interaction, the outcome is still largely cooperative and above all non-discriminatory. On the other hand, we find that a rather small amount of noise due to misperception (which is likely to occur in inter-group interaction) is sufficient for a discriminatory outcome.

Therefore the recommendation for software project management consists in enhancing un-

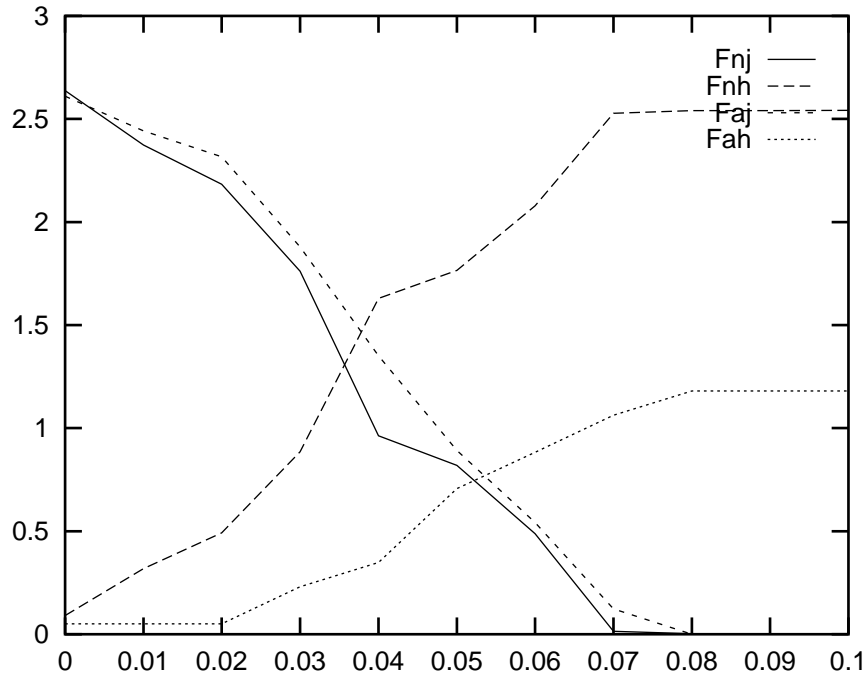


Figure 6: Native and alien fitness of Hyde- and Jekyll-type strategies for different noise levels

terstanding among different groups by means of providing the necessary learning environment and sufficient facilities for training and information, such as offering courses and seminars where the project participants can learn about the problems their partners are faced with, and the solutions and tools they apply. These measures are aimed at narrowing the cultural gap between organizations in order to decrease the probability of misunderstanding which has been shown to be of high importance to project success or failure.

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