Cooperation in Hunting and Food-Sharing: A Two-Player Bio-inspired Trust Model

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Abstract. This paper proposed a new bilateral model supporting cooperative behavior. It is inspired by cooperation in hunting [34,38] and food sharing of female vampire bats [56,57,58]. In this paper, it is postulated, that low bounding of food capacity (fast saturation) in conjunction with a high demand of food energy (fast starving without food) strongly supports cooperative behavior. These postulations are integrated within the proposed model as an extension of the prisoner dilemma [10,11,49].

Keywords: bio-inspired models, trust management, self-organizing communities, cooperative systems, cooperative hunting, food sharing behavior, vampire bats.

1 Problem

From a collective perspective cooperative behavior is very important, but at first sight not of an individual perspective. The simple analysis of cooperative behavior in prisoner dilemma advises non-cooperation as the dominant strategy in the case of a lack of trust between the players [10,11,49]. But in nature many animals are not opportunistic, in fact they show cooperative behavior among each other in many cases. A lot of research took place to explain the differences between the advised dominant strategy from game theory compared to cooperative behavior in nature; e. g., iterated games [3], evolution-inspired games (kin selection [13,14], reciprocal altruism [27,33,48], master-and-servant strategy), sociological-inspired games (social identity theory [46,60]), or the possibility of punishment in case of non-cooperative behavior (folk theorem). But up to now, there is no satisfying explanation.

This is why, this paper focuses on interesting findings in biology concerning trust and cooperative behavior and found some inspirations of cooperative hunting behavior [34,38] as well as of food sharing behavior of vampire bats [56,57,58]. In this paper, it is postulated, that low bounding of food capacity (fast saturation) in conjunction with a high demand of food energy (fast starving without food) strongly supports cooperative behavior.

This paper is divided into 6 parts: After the problem description in section 1, a brief literature review concerning cooperation and competition in artificial intelligence is given in section 2. After that, some interesting aspects of cooperation

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and competition in nature are shown in section 3. On that biological-inspired basis, a new model as an extension of the basic iterated prisoner dilemma is proposed in section 4. In section 5 the proposed model is evaluated via simulation. Finally, in section 6 limitations of the work and future research directions are shown.

2 Cooperation and Competition in Artificial Intelligence

2.1 Game Theory

Despite of the fact, that trust and negotiations had already played an important role within the Babylonian Talmud [2], *G. Leibniz* [21] was one of the first who researched during the 17th century on concurrent and cooperative human behavior. *A. Cournot* [7] ascertained in the first half of the 18th century the main issues of negotiations in duopolies. Later, during the second half of the 18th century *F. Edgeworth* [9] and *J. Bertrand* [4] had proceeded the research, e. g., on graphical explorations, before *E. Zermelo* [61] provided the first mathematical formal approach on the basis of the Minimax-search in games in 1912. In 1921, *F. Borel* [6] introduced the concept of mixed strategies. On that basis, in 1928 *J. von Neumann* [53] proofed that every Two-Player-Game has a Minimax-Equilibrium in mixed strategies. Later, in 1944 *J. von Neumann* and *O. Morgenstern* [54] presented the influential work 'Theory of Games and Economic Behavior'. A further milestone was placed by *A. Tucker* [49] by the famous prisoner dilemma. *M. Dresher* [8] and *M. Flood* (e. g., [10,11,12]) from the *RAND Corporation* where the first who used systematically the prisoner dilemma in experiments. *R. Axelrod* [3] firstly implemented the prisoner dilemma in computer programs.

During the 1950ies and 1960ies most of the publications had focused on cooperative negotiation behavior. After that period, the research focus has moved to the non-cooperative branch. The most influential milestone in this research field was placed by *J. Nash* [30,31] with the later so-called 'Nash-Equilibrium'. *J. Nash* analyzed Two-person negotiation problems under the assumption of complete information. In 1960, *T. Schelling* [39] bridged game theory and general equilibrium conditions in an economy by introducing the 'focal point'. *W. Vickrey* [52] presented in 1961 the later so-called 'Vickrey-Auction Model' to identify true preferences of negotiation partners [52]. *R. Selten* [40,41,42] introduced the concept of 'Teilspielperfektheit' for sequential negotiations in 1965 and enormously stimulated business sciences with game-theoretical applications in the field of negotiations. Later, *D. Kreps* and *R. Wilson* [20] extended these works. A next important work was published by *J. Harsanyi* and *R. Selten* [16] by extending the work of *J. Nash* [29,30,31] to negotiation situations with incomplete information. One next step was the adaption of elements of the evolution theory into game theory. The corresponding concept of 'Evolutionary Stable Strategies' was introduced by *J. Smith* [47] in 1972. Finally, strategic behavior and interactions between self-interested agents were firstly analyzed by *J. Rosenschein* and *G. Zlotkin* [36,37,62] on the basis of the fundamental game-theoretic work [54,15,16,19].

2.2 Artifical Intelligence

The basis of Artificial Intelligence (AI) was generated by *W. McCulloch* and *W. Pitts* [26]. They proposed a biological-inspired artificial neural network based on the formal logic of *A. Whitehead* and *B. Russell* [55] and the Turing machine of *A. Turing* [50,51]. In 1956, *J. McCarthy* [25] introduced the name 'Artificial Intelligence' during a workshop in Dartmouth, New Hampshire, USA. *J. McCarthy* [24,23] defined AI as the science to design intelligent machines or rather intelligent programs.

Further major milestones in AI research had placed by *H. Simon* and *A. Newell* [32] with the 'General Problem Solver' and by *E. Shortliffe* [44,43] with the expert system 'MYCIN', before *M. Minsky* [28] postulated the thesis that 'intelligence' is generated by the interaction of a lot of simple modules. That was the key assumption to pave the way for 'Distributed Artificial Intelligence' (DAI).

2.3 Software Agents as Biological-inspired Programs

Software agents were developed as a part of DAI research. Within this research area, 'Distributed Problem Solving' (DPS) can be separated from 'Multi-Agent-Systems' (MAS). The concept of a software agent is based on the actor model by *C. Hewitt* [18]. The local node within a DPS system is not independent from the system [5]. In contrast, in MAS a software agent is independent and decides its participation by its own [36]. Key biological-inspired characteristics of software agents are autonomy, social ability, reactivity and pro-activeness [59]. Because of this characteristics, in an MAS is no supervisor who controls the software agents, particularly punish non-cooperative behavior. Other trust-supported mechanisms are needed. Here, analogies can be found within animality. To support trust in cooperative behavior, some animals show solutions, especially in hunting scenes and food sharing.

3 Aspects of Cooperation and Competition in Nature

In nature many animals show cooperative behavior; e. g., kin selection [13,14], reciprocal altruism [27,33,48], cooperative hunting [34,38], or food sharing [56,57,58]. In the following it is focused on cooperative hunting behavior and on food sharing behavior of vampire bats.

3.1 Cooperative Hunting

C. Packer and *L. Rutton* [34] reviewed the cooperative hunting literature and analyzed the advantages and problems of cooperative hunting. In case of a larger prey, cooperative hunting is often the observed strategy in nature. *D. Scheel* and *C. Packer* [38] generally pointed out that cooperative behavior in hunting depends on the size of prey.

However, *C. Packer* and *L. Rutton* [34] reviewed data from 28 studies of group hunting and showed that hunting success generally increases asymptotically with increasing group size in circumstances where individuals are expected to hunt cooperatively. In small groups every individual is needed and have to participate to be successful in hunting.

3.2 Food Sharing Behavior of Female Vampire Bats

G. Wilkinson [56,57,58] have extensively researched on food-sharing behavior of female vampire bats (lat. 'desmodus rotundus'). He showed that food sharing by regurgitation of blood among wild vampire bats depends equally and independently on degree of relatedness. Vampire bats fail to secure a meal in approximately 10 percent of their foraging bouts, while approximately 33 percent of bats under two years of age fail [57]. Missed meals can have enormously effects on survival of the bats, because young vampire bats will starve to death after around 60 hours without a meal [58]. *G. Wilkinson* [56] found that reciprocal exchanges of blood meals by regurgitation are common between female vampires.

Female vampire bats live around 18 years. Group composition appears to be stable over long time [56,57]. This is why multiple interactions between the bats are most likely. Laboratory and field studies indicate that bats are significantly less likely to provide a meal to those bats who failed to reciprocate this action in the past [27, p. 275].

In summary, three major keys seems to support cooperative behavior:

(k_a) small groups, and
(k_b) a high demand of food energy (fast starving without food), and
(k_c) low bounding of food capacity (fast saturation).

4 Formal Model

4.1 Initial Assumptions

A1. There are two agents, A and B (see k_a).
A2. Each agent (A and B) acts rational within market economy conditions.
A3. Each agent (A and B) wants to maximize its own utility ($u_{A,B}$).
A4. Neither, A nor B has any information about the opponent.
A5. The game is played repeatedly (iterated game with $1..i..N$ rounds).

4.2 Basic Model

The basic model correspondents with the prisoner dilemma [10,11,49].

Definition 1. *At each round i, A and B can choose privately one of the following possible strategies $S(i)_{A,B} = [C, D]$:*

> **C̲ooperation:** *Here, the agent wants to cooperate and tries to share the cake fifty-fifty.*
> **D̲eception:** *Here, the agent tries to cheat.*

Definition 2. *Depending on the chosen strategy $S_{A,B} = [C, D]$ the following symmetric payoff function $[u_A|u_B]$ exists ($T > R > P > S$):*

$$[u_A|u_B] = f(S_A, S_B) = \begin{matrix} & \begin{bmatrix} S_B \end{bmatrix} \\ [S_A] & [u_A|u_B] \end{matrix} = \begin{matrix} \\ \begin{bmatrix} C \\ D \end{bmatrix} \end{matrix} \begin{bmatrix} C & D \\ R|R & S|T \\ T|S & P|P \end{bmatrix} \quad (1)$$

4.3 Model Extensions

E1. Each agents survive itself in the case of positiv energy ($e(i)_{A,B} \geq 0$).
E2. There is only a cake to divide or rather a payoff in the case of both agents A and B are alive ($e(i)_A \geq 0$ AND $e(i)_B \geq 0$). (For successful hunting in small groups every agent is needed and has to participate (see k_a).)
E3. At each round i, A and B have to spend s fix energy points (see k_b).
E4. The energy capacities of A and B are bounded to e_A^{max}, e_B^{max}. More energy payoffs from the payoff function $[u_A|u_B]$ runs to seed (see k_c).

5 Evaluation

According to [17], in order to show the utility, quality, and efficacy of the proposed model as a design artifact, it has to be evaluated via well-executed evaluation methods; e.g. by simulation. During a simulation the model will be checked with artificial data. Goal of the evaluation is to show the benefits of the proposed model compared to other models.

5.1 Simulation Setting

Five extended meta-strategies are utilized for simulation: 1. Strong Cooperation (COOP), 2. Strong Deception (DEC), 3. Random Cooperation or Deception (RAND), 4. Tit for Tat (TFT) [3], and 5. Tit for two Tats (TFTT).

5.2 Experimental Results

The simulation results of non-redundant combinations of the meta-strategies (COOP, DEC, RAND, TFT, TFTT) of A and B are presented in Tab. 2.

Table 1. Simulation Parameters

Parameter	Value(s)
Starting energy:	$e(0)_{A,B} = 6$
Fixed consumption energy:	$s = 3$
Energy capacity:	$e^{max}_{A,B} = 10$
Payoff matrix:	$T = 10, R = 5, P = 2, S = 0$

Table 2. Results

Strategy A	Strategy B	Rounds (i) Survive A	Rounds (i) Survive B
COOP	COOP	∞	∞
COOP	DEC	2	5
COOP	RAND	ND($\mu = 9.80; \delta = 8.09$)	ND($\mu = 13.20; \delta = 8.18$)
COOP	TFT	∞	∞
COOP	TFTT	∞	∞
DEC	DEC	6	6
DEC	RAND	ND($\mu = 6.20; \delta = 0.76$)	ND($\mu = 3.10; \delta = 0.92$)
DEC	TFT	6	4
DEC	TFTT	5	2
RAND	RAND	ND($\mu = 21.87; \delta = 20.07$)	ND($\mu = 21.60; \delta = 19.74$)
RAND	TFT	ND($\mu = 365.57; \delta = 349.49$)	ND($\mu = 364.53; \delta = 349.73$)
RAND	TFTT	ND($\mu = 52.37; \delta = 66.34$)	ND($\mu = 49.77; \delta = 66.66$)
TFT	TFT	∞	∞
TFT	TFTT	∞	∞
TFTT	TFTT	∞	∞

5.3 Discussion

As shown in Tab. 2 the extended model intensively supports cooperation. As long as no agent tries to cheat, both agents survive unlimited time. The special variants (TFT) and (TFTT) are leap of faith meta-strategies while(COOP) is the strong cooperation meta-strategy. When both agents use one of these meta-strategies they survive endlessly.

On the other hand, in all variants, deception is strongly punished. If one of the agents use (DEC) or (RAND) both agents die.

6 Conclusion

The proposed model strongly supports cooperation of agents (Tab. 2). Because of bounding of the energy capacities of both agents in combination with a high demand of energy at every round, agents in small groups are forced to be co-operative. These assumptions are inspired from nature and concern the trust in systems (general conditions, see *N. Luhmann* [22]), not the trust in other agents. Non-cooperation quickly ends in starving of both agents.

There are practical economic implications: Because of the possibility that agents can hoard money and goods, non-cooperative behavior is emphasized. To support cooperative behavior between agents in value-added chains, continuous low-level deprecation of money is an appropriate instrument, e. g., by a moderate inflation rate and a progressive wealth tax.

6.1 Limitations

The proposed model is limited to two agents (see assumption A1). Further, rational behavior of the agents is assumed. But, since [45] it is clear that real agents act bounded rational. Despite of a robustness check by variation of the parameters in table 1 the model was only checked with some artificial data. An intensive evaluation or a mathematical proof of the model would be helpful.

6.2 Further Research Directions

A first extension of the proposed model should be the relaxation to more than two agents. Furthermore, other meta-strategies (e. g., mixed-strategies, customized) should be considered within the evaluation. Finally, the suggested implications to economy (inflation rate and progressive wealth taxes) should be economically and politically checked.

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