# Bringing Heterogeneity in the Learning Process Consumat Agents Play the Prisoner's Dilemma [*]

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### Abstract

Axelrod's work on the prisoner's dilemma is one of the most discussed model of social cooperation. While many aspects of his computer simulations have been debated, their evolutionary mechanism has not yet received the same attention. We know people do not differ only in the way they act, but also in how they change their behavior - some may like safe routines, others risk with the new. Yet in formal models cultural evolution is taken to be an homogeneous process, such as the imitation of successful peers. In this paper we challenge this view and we propose an agent-based model that takes into account heterogeneity among individuals' learning strategies. The evolutionary mechanism is an adaptation of the consumat approach, originally developed by Wander Jager and Marco Janssen in order to explain consumer behavior.

## 1 Introduction

After more than thirty years from the publication of its early results, Axelrod's prisoner's dilemma tournament remains a cornerstone on evolutionary explanation of social cooperation. As it is well known, Axelrod [1] [2] organized a series of virtual tournaments of competing strategies playing an iterated version of the prisoner's dilemma. Quite surprisingly, TIT-FOR-TAT scored better than all the other more sophisticated strategies. Further computer simulations, inspired by the collaboration with the evolutionary biologist W. D. Hamilton, confirmed the result as extraordinary robust. Axelrod's conclusion was that if a simple strategy such as TIT-FOR-TAT outperforms defection, cooperation can spontaneously emerge even among selfish individuals.

Over the years, scholars have been testing the robustness of Axelrod's conclusions as well as extending his model to incorporate some key features that were neglected in the original work. While most aspects have been widely discussed, the evolutionary mechanism has been left almost untouched. Yet it seems unrealistic to assume that all the individuals - or same individual in all circumstances - would engage in the same learning pattern, i.e. the simple imitation of successful neighbours. On the other hand, it is more reasonable to assume that individuals are heterogeneous even in the way they learn from experience and from others.

The aim of this paper is to propose an agent-model that accounts for a such an heterogeneity, adapting the consumat approach to the prisoner's dilemma. The consumat approach, originally formulated by W. Jager and M. Janssen [3] [4] to model consumer behavior, is a meta-model that allows agents to choose from a pool of learning strategies, which includes imitation as a special case. The choice depends both on the character of an agent and on the circumstances. We believe that the consumat approach can successfully model not only consumer behavior, but cultural evolution as well.

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# 2 The Consumat Approach

The consumat approach is a meta-model of human behaviour, originally developed by Jager[3]. The consumat approach aims at providing a unifying framework for partial models of individual behaviour. While a full exposition of the consumat approach is beyond the purpose of this article, we introduce its principles in the next section.

## 2.1 Fundamental insights

Social imitation or rational deliberation are just two possible examples of the many cognitive processes that people may engage in. According to the consumat approach, it is reasonable to suppose that (i) cognitive processes have different costs, in terms of the amount of information they need to compute (ii) cognitive processes can be more self-oriented or more socially-oriented (iii) the same individual tends to choose different cognitive processes in different circumstances (iv) different individuals have a different tendency in engaging in one particular cognitive process, at the expenses of the others.

What makes one cognitive process more relevant in comparison to others is the perceived satisfaction and uncertainty level. Satisfaction expresses the fulfilment of the different needs that individuals might have. It is reasonable to assume that individuals engage in expensive cognitive behavior only if highly unsatisfied, thus expecting that it is worth to invest a great amount of resources to improve their condition. Uncertainty refers to the confidence one has in her ability to understand the environment and act in an efficient way. If an individual does not feel confident, she would tend to imitate successful behavior of others, rather than deliberate on her own.

The consumat approach includes four different cognitive processes

1. Repetition of one's last action. Repetition is cheap in cognitive effort and individually determined. Hence, it is the choice of satisfied and confident individuals.

2. Rational deliberation, which aims at optimising one's utility, considering all the possible options and weighting all the available information. For this reasons, deliberation is cognitively expensive and individually determined. Hence, it is the choice of unsatisfied, but confident individuals.

3. Imitation of successful peers. Imitation is cheap in cognitive effort and socially determined. Hence, it is the choice of satisfied, but not confident individuals.

4. Inquiring involves deep social research[1]. Those who choose to inquire will consider the behaviour of all other individuals and imitate the most successful one. Inquiring is clearly more expensive than simple imitation, as the research undertaken is much wider.

Finally, individuals differ in ambition and uncertainty tolerance. This means that two different agents may regard the same material circumstances in different terms.

## 2.2 Adapting the Consumat Approach to the Prisoner's Dilemma

The consumat approach has been introduced to model consumer behavior, but it has been successfully applied into a number of different context. For example, Speelman and Jager [7]

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[1] The inquiring process was not present in the first formulation of the consumat approach. It has been introduced by Jager and Janssen[5] in 2012.

models farmers deciding which crop to grow and Jager and Janssen[6] models demographic dynamics. In this section, we introduce the adaptation of the consumat approach to the prisoner's dilemma.

First, in the original consumat approach cognitive processes lead agents to choose among alternative actions. On the other hand, in the prisoner's dilemma we are interested in the evolution and diffusion of strategies rather than actions. Hence, we have decided that agents have to choose which strategy to adopt and that strategy in turn selects one of the two possible actions - cooperation or defection. For example, suppose that at time $t$ agents $i$'s strategy is ALWAYS-COOPERATE and agent $j$'s strategy is ALWAYS-DEFECT. If at time $t+1$ agent $i$ imitates agent $j$, her strategy becomes ALWAYS-DEFECT. Until her strategy changes again, agent $i$ will act according to her new strategy and defect in every interaction.

In the prisoner's dilemma, the four cognitive processes are defined as follows

1. Repetition - don't change your strategy.
2. Rational deliberation - adopt the strategy ALWAYS-DEFECT.
3. Imitation - among your neighbours, consider the one with the highest pay-off. If his pay-off is greater than yours, abandon your old strategy and adopt his.
4. Inquiring - the same as repetition, but consider all agents, rather than your neighbours only.

While in the consumat approach individuals have different kinds of needs, in the prisoner's dilemma the fitness of one agent simply corresponds to her average pay-off per interaction $E$. Each agent is defined by a satisfaction threshold $ST$ [0,1]. Agent $i$ is satisfied if

$$Ei > TP * STi$$

where $TP$ stands for temptation, which is the maximum pay-off obtainable.

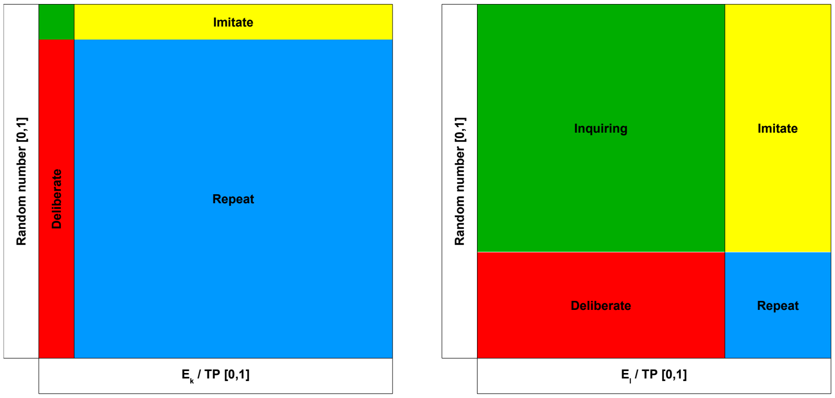
Each agent is also defined by a confidence threshold $CT$ [0,1]. Because it is not intuitive what could represent uncertainty in the prisoner's dilemma, CT simply stands as the chance of being confident at a given time. For example, suppose $CTi = .5$. This means that agent $i$ has equal chances of engaging in the individually driven processes and in the socially driven ones.

The two thresholds are different among agents, hence making agents heterogeneous in the way they evolve. For example, suppose $STk = .2$ and $CTk = .9$. Agent $k$ tends to repeat because easily satisfied and often confident - he rarely changes his strategy. On the other hand, suppose $STl = .7$ and $CTl = .3$. Agent $l$ tends to engage in social inquiring, because she is hard to satisfy and often confident. Figure 1 provides a graphical illustration of the characters of agent $k$ and agent $l$. It is evident how they would respond differently given the same material conditions - a given level of uncertainty (on the $y$ axis) and of fitness (on $x$ the axis).

## 3 Consumat Agents Play the Prisoner's Dilemma

Adapting the consumat approach to the prisoner's dilemma would be trivial if it did not lead to different results when compared to an homogeneous evolutionary mechanism, such as simple imitation. We introduce an agent-based model that runs both the simple imitation mechanism and the consumat one. We run the same experiment varying only the evolutionary mechanism and show that - at least for a reasonable parameter set - the final population is different.

The agent based model runs an iterated prisoner's dilemma. Pay-off are the usual ones - temptation = 5, reward = 3, punishment = 1 and sucker = 0. Each round, agents play one



(a) $STk = .2$ and $CTk = .9$ (b) $STl = .7$ and $CTl = .3$

Figure 1: Graphical representation of two possible agents' character, agent $k$ (a) and agent $l$ (b)

match of the prisoner's dilemma with all their neighbours. Evolution takes place every 100 rounds.

The population consists of thirteen equally represented strategies. Eight strategies were submitted by colleagues and include both popular ones, such as TIT-FOR-TAT, and original ones, such as HYSTERIC - which is a stochastic version of TIT-FOR-TAT. We have added four more classic strategies, such as ALWAYS-COOPERATE and RANDOM. Finally, we developed an original strategy called BAYESIAN. A BAYESIAN agent tries to understand what kind of strategy the opponent is playing and acts accordingly. For example, it defects if it thinks that its opponent is likely to keep cooperating. On the other hand, it cooperates if it thinks its opponent is likely to retaliate[2].

To test if consumat agents evolve differently from simple imitating ones we run the same experiment varying only the evolutionary mechanism. The common parameters are noise level (.05), kind of network (scale-free), size of population (about 340 agents) and length of the simulation (50 generations). The following results are averages of 100 repetitions for each experiment (see Figure 2)

If the chosen evolutionary mechanism is simple imitation the population becomes strongly dominated by the DIEKMANN strategy, while 10 of the 13 initial strategy disappear. DIEKMANN agents, which represent about the 91% of the final population, play just like TIT-FOR-TAT, but every 10th and 11th move cooperate unconditionally.

If we chose the consumat evolutionary mechanism the results are greatly influenced by the threshold parameters. It should be clear that pure imitation is a special case of the consumat approach and can be obtained if all agents are satisfied and not confident - e.g. for all agents, setting ST $=0$ and CT $=0$. As no empirical data are available to suggest exact values for the thresholds, for the following example we have arbitrary chosen the plausible values $ST = .2$ and $CT = .8$. $ST = .2$ means that, on average, agents are satisfied if they get at least the punishment pay-off[3]. $CT = .8$ means that, one average, agents are confident four rounds

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[2] The BAYESIAN strategy has been developed before knowing which strategies were going to be submitted. Hence, it has not been built *ad hoc* to recognize the strategies playing this tournament. It rather reasons for general patterns, such as being able to recognize if the opponent would retaliate after a defection.

[3] In fact, $temptation * ST = 5 * 0.2 = 1 = punishment$.

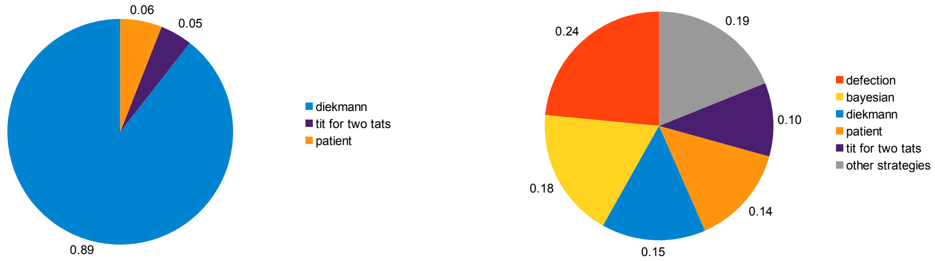

Figure 2: Simulation results for imitating agents (left) and for consumat agents, with average $ST$=.2 and average $CT$=.8 (right)

out of five. Combining these two values, we obtain that each round about half of the agents repeat, one-fifth imitate and deliberate and one-tenth inquire. A striking difference in the results is that this time neither strategy disappears nor dominates the population. The fact that no strategy disappears can be easily explained by the number of agents that repeat at every generation, resisting to change. ALWAYS-DEFECT is the most played strategy despite a poor average pay-off, because it is the choice of all the agents who deliberate, plus the ones resisting to change. The remaining four most common strategies are those who cope well with noise and which all get about the same average pay-off - BAYESIAN, DIEKMANN, PATIENT and TIT-FOR-TWO-TATS. Finally, the BAYESIAN strategy, which disappeared in the first experiment, outperforms all other strategies. This asymmetry can be explained by the fact that in the first experiment all the surviving strategies are not exploitable. Hence, exploring opponent's behavior with occasional defections does not pay. On the other hand, in the second experiment a few individuals of each strategy survive and BAYESIAN agents gain a little extra pay-off playing against them.

## 4 Discussion

Some people like routines, others enjoy trying new ways to do things. Some are ambitious, others easily satisfied. Moreover, the same individual can adopt different strategies depending on the context. However, most formal models of cultural evolution ignore such heterogeneity and assume that a uniform mechanism fits all individuals at all times. The aim of this paper is to challenge what we think is a poor representation of cultural evolution in the iterated prisoner's dilemma, which is typically modelled as the simple imitation of successful peers. We have proposed a first adaptation of the consumat approach. The formalization we introduce takes into account both the heterogeneity among individuals - which can be more or less prone to undertake one of the possible evolution patterns - and the fact that the choice of an individual can vary according to the circumstances. To test the consumat prisoner's dilemma against the traditional simple imitation, we have developed an agent-based model and run an experiment. Even if this experiment is meant to be only an example, we are satisfied with the results. First, they show that it is possible to obtain significantly different final populations with alternative evolutionary mechanisms. This reason alone should be sufficient to take the problem seriously and try to formalize the most plausible evolutionary mechanism we can and not the simplest one at hand.

We also think the consumat results are qualitatively more similar to the empirical data obtained from laboratory experiments, in which only a fraction of the individuals defect - in our example it is about half. Game theory and evolutionary models of the prisoner's dilemma make very different predictions. In fact, according to game theory we should expect an equilibrium of pure defection. If this forecast is clearly too pessimistic, evolutionary models - such as Axelrod's - suggest we should expect everyone to be nice unless provoked - playing some variant of TIT-FOR-TAT. Reality lies somewhere in between - just like the consumat approach seems to suggest.

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