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Continuous cooperation: A proposal using a fuzzy multicriteria sorting method

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A B S T R A C T

Unlike the proposal for a quantitative methodology for transforming discrete games into continuous ones, as in Golman and Page (2010) and Li et al. (2011), this article puts forward a tool that translates real-world cooperative behaviors into continuous levels of cooperation that will, in the next step, be sorted by predefined classes – low, medium and high cooperations – by means of a fuzzy multicriteria decision method. A numerical application was undertaken in order to illustrate the model proposed in a real world context modeled as a (modified) prisoners' dilemma.

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1. Introduction

Weber and Murnighan (2008) argue that groups and organizations face a fundamental problem: although they require cooperation, individuals are free to act as they wish. Therefore, these authors emphasize that the study of cooperation and the situations in which it can emerge is a subject of study in various fields of knowledge and there is a consensus about the fact that cooperation always carries risks.

For instance, in evolutionary biology, the origin and maintenance of cooperative or altruistic behavior is one of the most enduring, fundamental and intractable theoretical problems (Killingback and Doebeli, 2002). Moreover, as pointed out by Rand and Nowak (2013) “cooperation in a competitive world is a conundrum”.

When individuals, groups and nations are interdependent, mutual cooperation can lead to many benefits, while the incentives for non-cooperation can be very powerful. The literature presents several theories that address "the problem of cooperation" such as: Rational Choice Theory, models of expected utility and Game Theory, more specifically, through the study of "social dilemmas". They basically have one feature in common: individuals always try to maximize their personal utility. As a result, at least in theory, cooperative actions are hardly ever expected (Weber and Murnighan, 2008).

Attempting to understanding cooperation among selfish individuals is a long-standing puzzle, which has been studied by a variety of game models (Zhong et al., 2013). When the problem under consideration includes a conflict between two strategies – cooperation or non-cooperation – this can usually be modeled by the famous prisoner's dilemma, probably the most famous game in Game Theory (Bierman and Fernandez, 1998).

While Rand and Nowak (2013) state that among cooperative dilemmas, the most challenging one for cooperation is the prisoner's dilemma, in which two players choose between cooperating and defecting; cooperation maximizes social welfare, but defection maximizes one's own payoff regardless of the other's choice, Killingback et al. (1999) say that the “prisoners” dilemma is the common metaphor for the study of cooperation”.

For Rand and Nowak (2013), in what they called “the challenge of cooperation” – in a cooperative (or social) dilemma, there is tension between what is good for the individual and what is good for the population. The population does best if individuals cooperate, but for each individual there is a temptation to defect. A simple definition of cooperation is that one individual pays a cost for another to receive a benefit. Cost and benefit are measured in terms of reproductive success, where reproduction can be cultural or genetic.

Wahk and Nowak (1999a) claim that the prisoners' dilemma is the mathematical framework for the study of cooperation. The original game features a dichotomous situation regarding strategies and it has been of great interest that these strategies are continuous. According to Zhong et al. (2012), many studies insist on assuming this is a dichotomous situation regarding cooperation, namely cooperation or non-cooperation. These authors emphasize that this type of discrete

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strategy seems unrealistic in the context of real world problems. Verhoeff (1993), confirming this statement, argues that continuous versions of the prisoners' dilemma are rare and yet more realistic than their discrete analog versions. Finally, Killingback et al. (1999) argue that cooperation is rarely all or nothing, and its evolution probably involves the gradual extension of initially modest degrees of assistance.

Therefore, this paper puts forward a modified game (e.g. prisoners' dilemma), in which the strategies are provided in continuous interaction and derived from a previous study on the ranges of cooperation, using a multicriteria decision model that makes use of the problems set by classification, assuming that the inferences involved are fuzzy as a result of being inserted into a scene of vagueness and subjectivity. There are three semantics associated with the use of *fuzzy* sets and one of them expresses the preference relations between pairs of objects, used in outranking methods. Hence, the magnitude introduced by the use of fuzzy sets refines classical preference modeling and this is one of the domains where the application of fuzzy set theory can be very useful (Dubois and Prade, 1997).

2. A review of proposals for continuous strategies in cooperation games

Li et al. (2011) argue that fractional strategies mean that individuals are not absolutely cooperative or non-cooperative. They can simply adopt intermediate strategies. Several proposals have been made in order to work with continuous strategies, and these will be referred to later in this paper. However, there is a gap on proposals that point the way to selecting and to sorting intermediate ranges of cooperation.

Shutters (2013) says that many researchers have begun to move towards continuous versions of traditional games which because of the rich diversity of choices enable each player to be more reflective about the complexities of real world strategic situations. Moreover, "most previous studies presumed that interactions between individuals are discrete, but it seems unrealistic in real systems. Recently, there has been increasing interest in studying game models with a continuous strategy space" (Zhong et al., 2012); "In the real world, cooperation is often continuous" (Takezawa and Price, 2010); and "Allowing the moves to vary continuously in an interval brings a wider range of possibilities to the Iterated Prisoners' Dilemma" (Borges et al., 2007).

Some recent studies have made proposals for games with continuous strategies. The focus of most of them has been to present the game and then analyze the differences between the original game (discrete strategies) and modified game strategies (continuous) with respect to balance the dynamics and mechanisms (incentives) for cooperation.

For example, Li et al. (2011) generalize the prisoner's dilemma, with two strategies – cooperation and non-cooperation – in a game of multiple strategies in which the strategy s can take q different fractional values between zero and one. Verhoeff (1993) presents a continuous prisoner's dilemma in which players choose a number between zero and one, meaning the proportion of cooperation used in the game and having a payoff structure that is also continuous.

The work of Golman and Page (2010) presents the Stag Hunt game modified in that cooperation strategies are multiple, while there is only one strategy of non-cooperation. Tanimoto (2007) shows that intermediate strategies are equivalent to what in the literature on games is called mixed strategies that can be commonly interpreted as the probability that an individual does or does not cooperate, which may also be understood as until what point an individual does or does not cooperate. The papers cited here use the second interpretation as a starting point, namely, the possibility of employing fractional cooperation instead of the classical, dichotomous approach.

If on one hand, Bowles and Gintis (2004) offer a model of cooperation and punishment called "strong reciprocity": where members of a group benefit from mutual adherence to a social norm, strong reciprocators obey the norm and punish its violators, even though as a result they receive lower payoffs than other group members, such as selfish agents, who violate the norm and do not punish, and pure cooperators who adhere to the norm but free-ride by never punishing others.

On the other hand, according to Taylor and Nowak (2007), punishment or "strong reciprocity" (Boyd et al., 2003; Bowles and Gintis, 2004), is not a mechanism for the evolution of cooperation, but an extension of the basic game from two possible actions (cooperation and defection) to three (cooperation, defection and punishment).

Rapoport and Chammah (1965) show a version in which there is a number (>2) of discrete cooperative strategies, but there is nothing about continuous strategies. Li et al. (2011), however, propose a structure for cooperation with q strategies where each strategy s of a set of strategies S can assume the following values $\{0,\ 1/q-1\ ,\ 2/q-1\ ,\ \dots,\ q-2/q-1\ ,\ 1\}$. The idea of their paper is that the number of q strategies is so large that there is a context of ongoing cooperation, which would be more consistent with reality, as can be seen below:

$$s \in \left\{0, \frac{1}{q-1}, \frac{2}{q-1}, \frac{q-2}{q-1}, 1\right\} \tag{1}$$

$$\text{If } q=2 \quad s \in \{0, 1\} \tag{2}$$

$$\text{If } q=3 \quad s \in \left\{0, \frac{1}{2}, 1\right\} \tag{3}$$

$$\text{If } q=4 \quad s \in \left\{0, \frac{1}{3}, \frac{2}{3}, 1\right\}$$

$\vdots$

$$\text{If } q \to \infty \text{ proposals for continuous strategies} \tag{4}$$

As can been seen, all these proposals can represent the context of discrete strategic cooperation, since this is a special case of the continuous version.

There is a range of applications of Game Theory in problems dealing with the dynamic evolution of some phenomenon or analyzing strategies using continuous cooperation (Day and Taylor, 2003; Scheuring, 2005; Wahk and Nowak, 1999a,b; Harrald and Fogel, 1996; Killingback et al., 1999; Killingback and Doebeli, 2002; Jimenez et al., 2009; Mendez-Naya et al., 1995; Andre and Day, 2007).

While there are several proposals for games with continuous cooperative strategies, what is noticeable is the lack of studies that indicate a systematic way to determine and classify them. Another important point, as Shutters (2013) highlighted – with respect to the work of Doebeli et al. (2004), is that translating the qualitative game description into a formula can create an overly simple and overgeneralized formula that may lead to errors in classifying which game is actually being modeled. In other words, this paper presents some of the pitfalls of moving from discrete games to their continuous counterparts. See also Doebelli et al. (2013).

The next section discusses the fuzzy multicriteria decision methodologies to be used in this study in order to achieve the desired results.

3. Fuzzy multicriteria decision

Fuzzy multicriteria methodologies have been widely used in many problems. Some recent papers show how these are applied

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