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Achieving multiple goals via voluntary efforts and motivation asymmetry

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ABSTRACT

The achievement of common goals through voluntary efforts of members of a group can be challenged by the high temptation of individual defection. Here, two-person one-goal assurance games are generalized to N-person, M-goal achievement games in which group members can have different motivations with respect to the achievement of the different goals. The theoretical performance of groups faced with the challenge of multiple simultaneous goals is analyzed mathematically and computationally. For two-goal scenarios one finds that "polarized" as well as "biased" groups perform well in the presence of defectors. A special case, called individual purpose games (where there is a one-to-one mapping between agents and goals for which they have a high achievement motivation) is analyzed in more detail in form of the "importance of being different theorem". It is shown that in some individual purpose games, groups can successfully accomplish several goals simultaneously, such that each group member is highly motivated toward the achievement of one unique goal. The game-theoretic results suggest that multiple goals as well as differences in motivations can, in some cases, correspond to highly effective groups. Applying this approach to the case of winemakers making disease control decisions in their respective vineyards shows that game outcomes need not depend on the heterogeneity in the resource value, as previously thought, but they could be more generally driven by motivation asymmetry.

1. Introduction

Reaching goals represents a key ability of intelligent agents. Reaching a goal in a way that requires the contribution of several agents can be modeled as a game: An assurance game is a game-theoretic model, in which members of a group can choose to spend individual efforts or resources for the achievement of a common goal (Sen and Majumdar, 1969). The choice of exerting an effort toward a goal has a cost (a negative utility), the achievement of the goal has a benefit (positive utility) for each group member. The original formulation of the assurance game corresponds to two agents, one goal and two choices per member of contributing a high effort or a low effort toward that goal. Other names for this class of games are coordination game, trust dilemma or stag hunt (based on a hypothetical scenario proposed by the philosopher Jean-Jacques Rousseau in which two hunters can choose to hunt a stag corresponding to a large payoff or a hare corresponding to a small payoff; the catch is that successfully hunting the stag needs both hunters to choose that option) (McAdams, 2008; Skyrms, 2004).

Such situations can be analyzed within the framework of non-cooperative game theory, in which participants (interchangeably referred to as players, actors, agents or persons) can choose among different actions and strategies in order to maximize their expected outcome. The key concept is that of a (Nash) equilibrium, in which no player can unilaterally improve the outcome by changing the strategy (Nash, 1951).

The classic assurance game comprises three Nash equilibrium points: two pure-strategy equilibria corresponding to mutual cooperation and to mutual defection in addition to one mixed-strategy equilibrium point in which both agents choose between cooperation and defection with probability 1/2.

Milinski et al. studied experimentally iterated assurance games performed by groups with six members, each of whom possesses fine-grained donation options in order to potentially obtain a common-pool reward provided the combined donations of the group are at least as high as a certain threshold (Milinski et al., 2008). Also, it has been noted that the outcome of collective action challenges may depend not only on the rewards but also on the structure of communication networks (Chwe, 2000). In an

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inter-species comparison, it has been found that game theoretic considerations influence the decision making in assurance games not only in humans but also in chimpanzees and (to a lesser extent) capuchin monkeys (Brosnan et al., 2011). In the case of wild chimpanzees, the behavior as well as the payoff structure of achieving the common goal of obtaining prey via hunting in a group versus alone has been shown to depend on the local circumstances such as hunting success rates and access to meat by non-hunters (Boesch, 1994).

The games typically analyzed by game-theoretic analysis deal with scenarios to reach one particular goal (McCain, 2010). Groups are, however, frequently faced with multiple simultaneous challenges: families are challenged with raising children and earning money; societies are challenged with helping those in need, while simultaneously protecting their members from threats. These can be viewed as challenges similar to those found in multi-attribute negotiations, in which participants possess different motivations with respect to different objectives (Lai et al., in press). Multi-attribute game theory has been applied to auctions (Bichler, 2000), border security patrolling (Aguirre et al., 2011) and supply chain network negotiations (Yu et al., 2013).

Because the different choices for the differently motivated participants quickly leads to a “combinatorial explosion” of possibilities, the tractability associated with non-cooperative games can become an issue, thus leading researchers to, for example, “issue-by-issue” analysis approaches of multi-attribute games (Lai et al., in press). An issue-by-issue approach is to tackle one goal at a time. This seems at first sight a plausible strategy, but it eliminates important solutions early on. For example, imagine a situation where there are two different goals *I* and *II* and two participants *A* and *B* such that solving goal *I* is important to participant *A* and achieving goal *II* is important to participant *B*. Considering both goals with both participants simultaneously may lead to the solution that participant *A* is tackling goal *I*, while participant *B* is tackling goal *II*. In contrast, in an issue-by-issue approach, there will be a negotiation for goal *I* and a separate negotiation for goal *II*. Both negotiations are in danger of breakdown where no goal is achieved, because in each negotiation one participant has low motivation and appears as “defector”.

Here we extend the assumptions underlying assurance games to include those that describe a general achievement game that allows for multiple goals and multiple strategy options per goal for each agent. No requirement is made that the utilities of each agent with respect to each goal are identical (in other words symmetry is not required). Nor is the requirement made that the agents agree on a common strategy (in other words we incorporate a non-cooperative game-theoretic model). This extension to multiple goals is important, because it leads to solutions (i.e. equilibria where goals are achieved) that are not apparent if one considers goals in isolation. The goal of the study is to systematically ascertain how groups consisting of agents with diverse motivations are predicted to perform with respect to multiple simultaneous challenges. This theoretical work may be important for improving the effectiveness of voluntary efforts of groups with respect to achieving non-profit goals. In this study it is explored to what extent multiple simultaneous challenges offer opportunities for goal achievement that are not available in single-goal situations. The need for an improved understanding of such situations is particularly apparent with respect to environmental goals, where a large number of agents with diverse motivations are challenged with prioritizing environmental, economic and other goals.

The *importance of being different* theorem is presented, that states that a group of N agents faced with achieving N goals, and individual motivations in which each agent is uniquely motivated to spend the effort to solve one particular goal leads to one unique Nash equilibrium point that corresponds to a situation in which all goals are achieved. This theorem reduces – in applicable situations – the need for detailed computer simulations, and facilitates communicability and intuitive understanding of potentially complex game-theoretic situations. These theoretical considerations are augmented by computer results that correspond to group sizes ranging form 2 to 5 faced with the challenge of achieving 1, 2 or 3 goals. Both theoretical and computer results indicate that multiple goals and motivation asymmetry can facilitate the achievement of goals without invoking the requirement for iteration or other mechanisms such as reciprocity. Next, an example application is presented in Section 5, where the theory is applied to the case of winemakers and their efforts to invest in disease control measures in their respective vineyards.

The developed approach for achieving goals based on diverse individual motivations can be expected to be rather robust and simple compared to situations where additional mechanisms for achieving compliance are needed. Secondly, the presented solutions are applicable to situations, where only a minority is motivated to achieve certain goals and enforcing mechanisms like coercion are not reliably available because they would need a motivated majority. In other words, the developed theory may have implication for innovative policy-making for cases where traditional approaches have not succeeded. Examples related to viticulture, biodiversity loss and recycling are presented.

2. The multi-goal achievement game

Let there be a scenario in which a group of N agents is faced with the challenge of achieving M different goals. A formal definition of an N-agent, M-goal achievement game is presented below; note that the function $\Theta : \mathbb{R} \rightarrow \{0, 1\}$ stands for a variant of the Heaviside step function: $\Theta(x) = 1$, if $x \geq 0$ and $\Theta(x) = 0$, if $x < 0$.

Definition 1. Multi-goal achievement game Let there be a set of $N \in \mathbb{N}$ different agents, a set of $M \in \mathbb{N}$ different goals, a number $K \in \mathbb{N}, K > 1$ and a cost set $C = \{c_k | k \in \{1, \ldots, K\}, c_k \in \mathbb{R}, c_k \geq 0, c_{k_1} < c_{k_2} \Leftrightarrow k_1 < k_2\}$. Each agent $i \in \{1, \ldots, N\}$ can for each goal $j \in \{1, \ldots, M\}$ choose between spending $d_{ij} \in C$ currency units toward the achievement of goal j. Let D be the $N \times M$ matrix consisting of the elements d_{ij}. Let there be an M-tuple of positive goal thresholds $T = (g_1, g_2, \ldots, g_M) \in \mathbb{R}^M$. We say goal j is achieved, if and only if $\sum_{i=1}^{N} d_{ij} \geq g_j$. Let the utility of agent i be the negative of the sum of payments of agent i plus a sum of rewards obtained via achieved goals, in other words $u_i(D) = -\sum_{j=1}^{M} d_{ij} + \sum_{j=1}^{M} w_{ij} \Theta\left(\sum_{k=1}^{N} d_{kj} - g_j\right)$ with $w_{ij} \in \mathbb{R}$. We call w_{ij} the motivation of agent i with respect to goal j. Let W be the $N \times M$ matrix consisting of the elements w_{ij}. We call the matrix W the motivation matrix of the game. We call the finite, non-iterative N-player game $G(N, M, C, T, W)$ an M-goal achievement game or an N-player, M-goal, K-choice achievement game. If $M > 1$, we call the game a multi-goal achievement game, otherwise a single-goal achievement game.

The utility (i.e. total payoff) of an agent is thus the sum of the negative of the chosen payments plus rewards for achieved goals. Note that the reward of an agent i to achieve a particular goal j (represented by motivation matrix elements w_{ij}) can consist of a material reward or a subjective motivation or combinations thereof. The motivation matrix elements can nonetheless be measured in currency units (not in terms of financial rewards but in the sense of the willingness to pay for achieving a certain goal).

Motivation is used in this paper as a word for describing the part of the payoffs corresponding to goal achievement not including the chosen payments. The motivation of an agent in connection with one goal can be viewed as the maximum willingness-to-pay of an