



Control of the socio-economic systems using herding interactions

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HIGHLIGHTS

- We introduce a fixed number of controlled agents into the agent-based herding model.
- The impact of the controlled agents depends only on their number.
- The proposed model may be considered as an explanation of the leadership phenomenon.

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ABSTRACT

Collective behavior of the complex socio-economic systems is heavily influenced by the herding, group, behavior of individuals. The importance of the herding behavior may enable the control of the collective behavior of the individuals. In this contribution we consider a simple agent-based herding model modified to include agents with controlled state. We show that in certain case even the smallest fixed number of the controlled agents might be enough to control the behavior of a very large system.

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1. Introduction

Collective behavior observed in many complex systems cannot be understood as a simple sum or average over the behavior of the individual interacting parts [1]. When considering complex socio-economic systems it is irresistible to see the endogenous interactions behind the spontaneous emergence of trends, norms or even mass panic. Such phenomena, especially panic, cannot simply emerge from the rational representative agent framework as the agent is assumed to act completely rationally [2–4]. Thus the contemporary socio-economic research needs to use a different framework to understand these phenomena better [5–10].

One of the suitable alternative frameworks is heterogeneous agent-based modeling [7–9]. This framework uses a generalized concept of the agent to represent the interacting parts of the modeled complex system. Interactions between them usually follow very simple rules, by the virtue of the agents' zero-intelligence or bounded rationality assumption. Such assumptions can be viewed just as a result of statistical irrelevance of a more detailed consideration. Despite the underlying simplicity, the complex collective behavior emerges as a result of the interactions [3,4,8,11–20]. One of the main ingredients of these simple rules and emergence of complex collective behavior is imitation, peer pressure and strong coupling [3,4,8,20].

Imitation, peer pressure and strong coupling between the agents may allow a possibility for a small fraction of the agents to make a significant impact on the collective behavior. The influence of the small number of individuals on the collective

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behavior of a crowd was studied in a series of experiments by Dyer et al. [21]. People participating in these experiments were asked to move randomly, but to stay with a crowd. Some of the people in a crowd, a small number of them, were asked to move in a certain direction. It was expected that they will be able to lead the whole crowd in that direction. The results of the experiment have shown that 4–10 directed individuals were enough to lead the crowds of up to 200 people. It is interesting to note that the necessary number of directed individuals grows slower than the total number of people in the crowd. Consequently the movement of even larger crowds could be also controlled in a similar fashion without a further significant increase in a total number, not percentage, of the directed individuals. In the context of this contribution we could see the directed individuals in the aforementioned experiment as the controlled individuals. Similar experiments were performed with animals by using controlled robots [22].

From a point of view of mathematical modeling a similar idea was previously tested in the well-known Prisoner's Dilemma setup by Schweitzer et al. [23]. The model was setup in a way to show that the herding behavior may enhance cooperative behavior instead of a more self-interested behavior.

We approach the modeling of the collective behavior control slightly differently. In this contribution we consider Kirman's agent-based model [24]. This simple model describes the two state system dynamics, where agents make decisions based on the individual preferences and herding. In the recent years an interplay of a different types of social behavior were broadly studied by the researchers from very different fields [25], yet we feel that Kirman's model is one of the simplest mathematical models for the social behavior. Consequently we will use Kirman's model to demonstrate the influence of the individuals with a fixed opinion, which does not change due to the endogenous activity, but does change only due to the exogenous factors. We will show that this influence may be used to control the behavior of a social system.

In Section 2 we will present a more detailed discussion on Kirman's agent-based herding model and its macroscopic treatment, which was previously done in Refs. [17,26,27]. In the following section, Section 3, we will deal with the introduction of the controlled agents and discuss their effect on the collective behavior of the system. And finally in the last section of this contribution we will provide a brief summary and discussion.

2. Kirman's agent-based herding model

In Ref. [24] Kirman pointed out that a group of entomologists and numerous economists have observed a very similar phenomena in rather different systems. The group led by Pasteels observed an ant colony with two identical food sources available [28,29]. At any given time the majority of ants used only one of the available food sources, though naturally one would expect that the both food sources would be exploited equally. It was also observed that from time to time the preferred food source was switched. Interestingly enough these switches were triggered not by the exogenous forces, but by the system itself. Similarly Becker [30] noted that some of the decisions in economical scenarios might also have a similar nature—humans also tend to act asymmetrically in apparently symmetrical setups.

Having taken the aforementioned, and other (see references of Ref. [24]) observations into account Kirman proposed a simple one-step transition model. Which in general case can be expressed via the following one-step transition probabilities [31]:

$$p(X \rightarrow X + 1) = (N - X)\mu_1(N, X)\Delta t, \quad p(X \rightarrow X - 1) = X\mu_2(N, X)\Delta t, \quad (1)$$

here N is a fixed number of agents in the system (one of the available states is occupied by X agents and the other by $N - X$ agents), while $\mu_i(N, X)$ are the transition rates. The overall transition rates in Kirman's model are composed of the idiosyncratic transition rate, σ_i , and herding behavior, h , terms. One can define the overall transition rates to be given by Refs. [17,26,27]

$$\mu_1(N, X) = \sigma_1 + hX, \quad \mu_2(N, X) = \sigma_2 + h(N - X), \quad (2)$$

or by

$$\mu_1(N, X) = \sigma_1 + \frac{h}{N}X, \quad \mu_2(N, X) = \sigma_2 + \frac{h}{N}(N - X), \quad (3)$$

which form of the transition rates is more appropriate depends on the interpretation of Kirman's model. In the first, Eq. (2), case it is assumed that all agents may interact with all other agents, or namely on a global scale. While in the second case, Eq. (3), the agents are assumed to interact only with the fixed number of other agents, or their local neighborhood. The main difference between the two forms is a different scaling of the herding induced transition rates. In the first case they grow linearly together with the system size, N , while in the second case they remain constant. The differences between these forms can be well understood from the point of view of network theory [32].

Note that the one-step transition probabilities, Eq. (1), scale similarly—as N^2 and N correspondingly. Thus we will further refer to these interpretations as the non-extensive and extensive. Identical reasoning and terminology is also used in the previous works by Alfarano et al. [26,27,32].

The different scaling of the one-step transition probabilities implies the essential difference in the macroscopic behavior of these two interpretations of Kirman's model. In the non-extensive case the macroscopic dynamics, for $x = X/N$, (in the limit $N \rightarrow \infty$) are well described by the stochastic differential equation [17,26]:

$$dx = [\sigma_1(1 - x) - \sigma_2x]dt + \sqrt{2hx(1 - x)}dW, \quad (4)$$

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