Information Fusion 43 (2018) 57–65

Contents lists available at ScienceDirect

Information Fusion

journal homepage: www.elsevier.com/locate/inffus

A survey on the fusion process in opinion dynamics

Yucheng Dong[a,*], Min Zhan[a], Gang Kou[b,*], Zhaogang Ding[c], Haiming Liang[d]

[a] Business School, Sichuan University, Chengdu 610065, China
[b] School of Business Administration, Southwestern University of Finance and Economics, Chengdu 611130, China
[c] School of Public Management, Northwestern University, Xi'an 710069, China
[d] School of Economics and Management, Xidian University, Xi'an 710071, China

ARTICLE INFO

Keywords:
Fusion process
Opinion dynamics
Consensus
Group decision making

ABSTRACT

Opinion dynamics is a fusion process of individual opinions, in which a group of interacting agents continuously fuse their opinions on the same issue based on established fusion rules to reach a consensus, polarization, or fragmentation in the final stage. To date, many studies have been conducted on opinion dynamics. To provide a clear perspective on the fusion process in opinion dynamics, this paper presents a review of the framework and formulation of opinion dynamics as well as some basic models, extensions, and applications. Based on the insights gained from prior studies, several open problems are proposed for future research.

1. Introduction

In social phenomena, humans are the basic elements, and human behaviors depend on many variables. The most important factors behind human behavior are opinions and beliefs that drive actions [1]. Therefore, understanding the process of opinion fusion is key to explaining human choices.

Opinion dynamics is the study of the opinion fusion process [2] through interactions among a group of agents. Opinion dynamics research originated in France [3], and some interesting opinion dynamics models with different opinion formats and fusion rules have since been proposed, such as the DeGroot model [4,5], voter model [6–9], Sznajd model [10,11], majority rule model [12–14], Friedkin and Johnsen model [15,16], bounded confidence model [17–19], and continuous opinions and discrete actions model [20,21].

Opinion dynamics models are usually composed of a few basic elements - opinion expression formats, fusion rules, and opinion dynamics environments - and focus on three varieties of stabilized patterns: consensus, polarization, and fragmentation [18]. In the existing research, according to the different opinion formats expressed by agents, the models of opinion dynamics can be divided into two types: continuous opinion models (e.g., [4,5,17,18]) and discrete opinion models (e.g., [6–8,10,12,13,22]). Moreover, an agent will neither simply share nor completely disregard the opinions of other agents but will take these opinions into account to a certain extent in forming his/her new opinions in a process defined by a fusion rule. The fusion process in opinion dynamics is influenced by different opinion dynamics environments (e.g., social networks [23–25] and noise [26,27], etc.).

To provide a clear perspective on the fusion process in opinion dynamics, this paper presents a review of opinion dynamics. Moreover, with respect to insights gained from previous research, we aim to identify open problems and new directions for future research.

The rest of this paper is organized as follows. In Section 2, we introduce the framework and formulation of the fusion process in opinion dynamics. In Section 3, we review some basic models in opinion dynamics. Next, in Section 4, we introduce some extensions of opinion dynamics models. Following this, we survey the applications of opinions dynamics in Section 5. Subsequently, we provide and analyze open problems and new directions in opinion dynamics in Section 6. Finally, we present our conclusions in Section 7.

2. Framework and formulation of the fusion process in opinion dynamics

In this section, we will introduce the basic framework and formulation of fusion process in opinion dynamics.

Opinion dynamics is a fusion process of individual opinions in which interacting agents within a group continuously update and fuse their opinions on the same issue based on the established fusion rules and reach a consensus, polarization, or fragmentation in the final stage. The framework of the fusion process in opinion dynamics includes three key elements: opinion expression formats, fusion rules, and the opinion dynamics environment. Specifically, the agents in the group express

* Corresponding authors.
E-mail addresses: ycdong@scu.edu.cn (Y. Dong), minzhan2016@stu.scu.edu.cn (M. Zhan), kougang@swufe.edu.cn (G. Kou), zgding@nwu.edu.cn (Z. Ding), hmliang@xidian.edu.cn (H. Liang).

https://doi.org/10.1016/j.inffus.2017.11.009
Received 14 October 2017; Accepted 13 November 2017
Available online 21 November 2017
1566-2535/

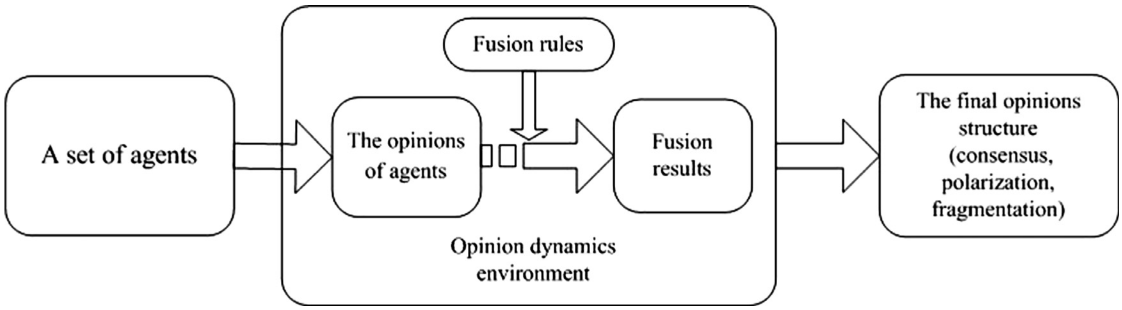

Figure 1. The framework of the fusion process in opinion dynamics.

initial opinions via a certain expression format, and then, according to fusion rules, the opinions of the agents are updated repeatedly. Finally, the opinions of all agents form a stable structure: consensus, polarization, or fragmentation. The framework of the fusion process in opinion dynamics is shown in Fig. 1.

Let $A = \{A_1, A_2, ...A_n\}$ be a set of agents, and let $x_i(t)$ be the opinion of agent A_i at time t. Let w_{ij} be the weight that agent A_i gives to agent A_j, where $w_{ij} \geq 0$ and $\sum_{j=1}^{n} w_{ij} = 1$. Then, the fusion process of the opinions of agent A_i can be described by

$$x_i(t+1) = w_{i1}x_1(t) + w_{i2}x_2(t) + ...+w_{in}x_n(t),\ t = 0, 1, 2, ... \tag{1}$$

Eq. (1) can be compactly written as

$$X(t+1) = W \times X(t),\ t = 0, 1, 2, ... \tag{2}$$

where $W = (w_{ij})_{n\times n}$ and $X(t) = (x_1(t), x_2(t), ...,x_n(t))^T \in R^n$.

All agents form a consensus if $\lim_{t\to\infty} x_i(t) = c (i = 1, 2, ...,n)$ for any $X(0) \in R^n$, where c is the consensus opinion [18,23]. On the other hand, two or more than two different opinions at the final stage indicate polarization and fragmentation, respectively.

3. Some basic models in opinion dynamics

In this section, we review some basic models in opinion dynamics, namely the DeGroot model, the bounded confidence model, and the voter model. These baisc models are generally used as a basis to develop the extensions of opinion dynamics models

3.1. DeGroot model

The DeGroot model [4] is generally considered the classical model in opinion dynamics. When W does not change over time or with opinions, Eq. (2) is called the DeGroot model. In the DeGroot model, the agents' opinions are continuous, and it is generally assumed that $x_i(t) \in R$.

DeGroot [4] proved that the consensus opinion is a linear combination of the initial opinions of all agents, and the combinational coefficients are related to the eigenvector associated with the eigenvalue 1 of the matrix W. Berger [5] presented a sufficient and necessary condition to reach a consensus in the DeGroot model, showing that all agents will form a consensus if and only if there exists $t^* \in \{1, 2, ...\}$ such that the matrix power W^{t^*} contains at least one strictly positive column. The results presented in DeGroot [4] and Berger [5] have been used as a basis for determining whether and how consensus can be reached in the social network DeGroot model [23].

3.2. Bounded confidence model

The weights in Eq. (2) may change with time or with opinion; accordingly, some elegant and concise variants of the DeGroot model have been proposed, such as the Friedkin–Johnsen model [15,16], the time-variant model [18], and the bounded confidence model [18,28]. In particular, the fusion rule of the bounded confidence model is becoming a popular tool in model opinion dynamics due to its consideration of psychological factors. In the bounded confidence model, an agent's opinion will only be influenced by agents whose opinions differ from his/her own no more than a certain confidence level.

In the bounded confidence model, we consider a set of agents $A = \{A_1, A_2, ...,A_n\}$, where each agent $A_i \in A$ has an opinion $x_i(t) \in [0, 1]$ at a discrete time $t \in \{0, 1, 2, ...\}$. Let $X(t) = (x_1(t), x_2(t), ...,x_n(t))^T$ be the opinions profile of all of agents at time t, and let ε be the bounded confidence. If the ε values are the same for different agents, the bounded confidence model is homogeneous; otherwise, it is heterogeneous [29]. The Deffuant–Weisbuch (DW) model [28] and the Hegselmann–Krause (HK) model [18] are two representative bounded confidence models that we will examine more closely.

(1) The Deffuant–Weisbuch model

In the DW model [28], two agents are randomly selected from the set of agents. Then, based on the bounded confidence, the two agents decide whether to communicate. There is no loss of generality if the agents A_i and $A_j (i \neq j)$ are randomly selected at time t. Then, if the difference between the opinions of agents A_i and $A_j (i \neq j)$ is smaller than bounded confidence ε at time t, i.e., $|x_i(t) - x_j(t)| \leq \varepsilon$, then they fuse their opinions according to

$$\begin{cases} x_i(t+1) = x_i(t) + \mu(x_j(t) - x_i(t)) \\ x_j(t+1) = x_j(t) + \mu(x_i(t) - x_j(t)) \end{cases},\ t = 0, 1, 2, ... \tag{3}$$

where $x_i(t+1)$ denotes the opinion of agent A_i at time $t+1$, and $\mu \in [0, 0.5]$ is the convergence parameter. The parameter μ controls an agent's movement toward the opinion of the other agent if the distance between them is less than ε [1,30]. If $\mu = 1/2$, the two agents will fuse to the average of their opinions the next time.

(2) The Hegselmann–Krause model

The HK model [18] is similar to the DW model [28]. In the HK model, let $I(A_i, X(t))$ be the confidence set of agent A_i at time t, and let $w_{ij}(t)$ be the weight that agent A_i distributes to agent A_j at time t. Then

$$w_{ij}(t) = \begin{cases} 1/\#I(A_i, X(t)), & A_j \in I(A_i, X(t)) \\ 0, & A_j \notin I(A_i, X(t)) \end{cases},\ i = 1, 2, ...,n, \tag{4}$$

where $I(A_i, X(t))=\{A_j \| x_i(t) - x_j(t)| \leq \varepsilon\}$ and $\#I(A_i, X(t))$ is the number of agents in the set $I(A_i, X(t))$.

The opinion $x_i(t+1)$ is then calculated as

$$x_i(t+1) = \sum_{A_j \in I(A_i, X(t))} w_{ij}(t)x_j(t),\ i = 1, 2, ...,n \tag{5}$$

The DW model and the HK model both rely on the idea of repeated averaging under bounded confidence. They differ in their fusion regime: In the DW model, agents meet in random pairwise encounters after which they do or do not compromise; in the HK model, each agent moves to the average opinion of all agents who lie in his/her area of confidence. Notably, the HK model is more suitable for modeling situations like formal meetings, where interaction occurs in a large group, while the DW model is better suited for pairwise interactions within large populations [31]. The similarities and differences between