# Follow the Leader: Profiling Agents in an Opinion Formation Model of Dynamic Confidence and Individual Mind-sets

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## Abstract

*We present and analyse a model of opinion formation with dynamic confidence in agent-mediated social networks where the profiling of agents as leaders or followers is possible. An opinion leader is specified as a highly self-confident agent with strong opinions. An opinion follower is attracted to those agents in which it has more confidence. In our model, an agent $i$ increases its confidence in another agent $j$ based on how well $j$'s opinion meets the criteria specified in $i$'s* mind-set*. A mind-set represents the set of beliefs, attitudes, assumptions and tendencies that predetermine the way an agent evaluates a received opinion. It is observed that the opinion formation in a group of persuadable agents, with similar confidence in each other, can easily lead to* groupthink *with agents following each other and one (or some) following the opinion of a single opinionated agent (i.e. an opinion leader). However this can be prevented by having at least one more self-confident, opinionated agent with an alternative opinion. This shows that divergent opinions from opinionated agents inhibit consensus. Furthermore, it is seen that once an* equilibrium *in the opinion formation has been reached, paradigm shifts can occur as the result of the sudden appearance of alternative opinion leaders.*

## 1 Introduction

We are interested in formalising, modelling, simulating and analysing the opinion formation dynamics of social scenarios where individuals can benefit from pervasive sources of information. Such scenarios include: politics and election campaign awareness; risk assessment (before), crisis management (during) and disaster recovery (after) in natural disasters, terrorist threats and large-scale technological incidents, etc.

The following scenario in politics illustrates the notion of opinion formation. We focus on the political campaigning period prior to governmental elections. On the one hand we have agents with a fixed political stance (*mind-set*) representing political parties and candidates campaigning their views (*opinions*) on certain policy issues. Political parties usually have opposite and fixed stances about an issue (e.g. left-wing and right-wing). Candidates can be modelled as opinionated agents having high self-confidence and strong opinions. On the other hand we have agents representing people (the electorate) who form their opinions (and eventually vote accordingly) by considering and following the proposals of the parties, the opinions of fellow citizens and their own opinions.

Electoral campaigns usually bring up discussion and public debate on a set of complex issues: environment, health, education, etc. Every person has an *initial opinion* on the issues and a degree of *confidence* about them. But as exchange of opinions takes place they might change their opinion on the issues following their mind-sets (e.g. environmentalist, neo-liberalist, feminist, etc.)

Arguably, it would be expected that the confidence in a political party increases as agents from the electorate align their opinions (lead by their mind-sets) with the candidates' views on different issues (or indeed vice versa). And that the vote could be correlated with the confidence in the parties. Consequently candidates become opinion leaders and the electorate opinion followers.

The aim of this paper is to present and analyse a model of opinion formation with dynamic confidence in agent-mediated social networks where the profiling of agents as leaders or followers is possible. Profiling in our model relies on the idea of abstracting the agent's beliefs, attitudes, assumptions and tendencies as its mind-set. Then agents evaluate the utility of the opinions based on the *affinity* between mind-sets and opinions. Positive evaluations increase the confidence in other agents and make an agent follow those opinions. Agents which follow no one, have strong opinions, and who are followed become opinion leaders.

The mathematical formalisation of the model is pre-

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sented in Section 2. Section 3 presents some definitions based on the model and agent profiling. Section 4 examines in detail some of the main properties of the model, including the "lemming effect" and paradigm shifting. Previous work on opinion formation models is discussed in Section 5. Finally Section 6 summarises these properties and discusses some assumptions of the model that will be withdrawn in future work.

## 2 Opinion Formation Model of Dynamic Confidence and Individual Mind-sets

In specifying agent societies we adopt a graph theoretical approach by defining agents as the nodes and *confidence relations* between agents as the vertices of a social network. We define each society as a directional, weighted, network, $G = (\mathscr{N}, \mathscr{W})$, consisting of a $n$-node set of agents $\mathscr{N}$ and a family of confidence functions $\mathscr{W} = \{w_1, w_2, \ldots, w_n\}$ where each function $w_i$ is of the form $w_i : \mathscr{N} \times T \rightarrow [0, 1]$.

Each confidence function $w_i(j, t)$ assigns a real value between 0 and 1 to the confidence relation between the ordered pair $\langle i, j \rangle$, indicating how much confidence $i$ has in $j$ at a specific time point $t \in T = \{0, 1, \ldots\}$. When $j = i$ the confidence function $w_i(i, t)$ yields a measure of *self-confidence*.

In line with Friedkin [8] and Hegselmann [10] we consider that for each agent the sum of the confidence in its acquaintances is always 1 (including itself), $\sum_{j=1}^{n} w_i(j, t) = 1$. The rationale for such consideration is that the measure of confidence is not based on absolute judgements but on relative ones. Thus, like in human societies, the confidence in one agent only increases and decreases with respect to the confidence in every other agent. For example, assume that an agent $i$ has only two acquaintances, agents $j$ and $k$. Also assume that at a given point $t$ the confidence in both is the same (i.e. $w_i(j, t) = w_i(k, t) = 0.5$). A relative increase in confidence in agent $j$ at time $t+1$ (e.g. $w_i(j, t+1) = 0.75$, and consequently $w_i(k, t+1) = 0.25$) does not imply an absolute negative assessment of the confidence in $k$, but only that at time $t + 1$, $i$ has more confidence in $j$ than in $k$.

Each agent holds information in the form of opinions, $o_i : T \rightarrow [0, 100]$. We adopt a continuous opinion approach, in line with [3, 8, 10], and consider an agent $i$'s opinion at time $t$, $o_i(t)$, as a real-valued statement between 0 and 100. An opinion communicates an agent's level of agreement about a raised issue. An issue is a subject-matter posing or querying a particular assertion about a topic. A *topic* is a socially-discussed subject. E.g. topic: nuclear power; issue: is nuclear power the best alternative to fossil-fuels?; opinion: $o_i(1) = 70$ (where $o_i(t) = 0$ conveys *total disagreement* and $o_i(t) = 100$ *absolute agreement* ).

We assume that each agent holds an initial opinion (i.e. $o_i(1)$) on every issue about to be discussed. However this opinion can change with time as agents are influenced by opinions exchanged with other agents. The influence that one agent's opinion exerts on another's is given by how much confidence, relative to other agents, the latter has in the former.

Correspondingly, the opinion formation dynamics consists of simultaneous opinion exchanges between pairs of agents and a subsequent individual opinion revision. The main objective of an agent is to collect opinions from other agents in order to revise (i.e. consolidate or modify) its own opinions. A secondary objective is to share its own opinions and influence other agents towards them.

The opinion formation dynamics occurs at discrete time points and on a per issue basis. At each time point each agent exchanges opinions with other agents. An agent $i$'s opinion changes at time $t + 1$ by weighting each received opinion at time $t$ with the confidence in the corresponding source (including its own opinion weighted by its self-confidence) such that:

$$o_i(t + 1) = \sum_{j=1}^{n} w_i(j, t) o_j(t) \tag{1}$$

The confidence between agents also changes with time. Agents start the opinion formation process with a predefined assignment of confidence in the potential exchange partners. As the first exchange happens and the opinion of each agent changes, the confidence changes accordingly.

One of the main characteristics of our model is that we assume that agents rely differently on other agents. Thus agents can have more confidence in some agents than others and this can change with time. In our model, an agent $i$ increases its confidence in another agent $j$ based on how well $j$'s opinion meets the criteria specified in $i$'s mind-set. A mind-set represents the set of beliefs, attitudes, assumptions and tendencies that predetermine the way an agent evaluates a received opinion. Assuming a positive evaluation for those opinions matching agent $i$'s mind-set and a negative for those contradicting it, then it can be said that the confidence in an exchange partner $j$ increases as $j$'s opinion matches $i$'s mind-set.

We specify the matching between agent $i$'s opinion and another agent's mind-set by defining an *affinity function* $a_i : \mathscr{N} \times T \rightarrow [0, 1]$. This function evaluates the linear similarity between an opinion and a given constant $\mu$ which is a representative reference value of an agent's mind-set for a given issue. Correspondingly we define the *affinity function* as:

$$a_i(j, t) = 1 - \frac{|o_j(t) - \mu_i|}{max|o - \mu_i|} \tag{2}$$

Where,

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$$max|o - \mu_i| = \begin{cases} 1 - \mu_i & \text{if } 0 \leq \mu_i < .5; \\ \mu_i & \text{if } .5 \leq \mu_i \leq 1. \end{cases} \quad (3)$$

$\mu$ is a constant different for each agent, different for each issue and constant in time. Thus in each time step, the *affinity* between agents can be different for each ordered pair of agents corresponding to the fitness between opinions and mind-sets.

Therefore, the confidence changes in time differently for each agent and based on the *affinity* between agents. Agents increase the confidence in those agents whose opinions fit their mind-set. Thus the confidence in other agents is redistributed according to the following equation:

$$w_i(j, t+1) = \frac{w_i(j,t) + w_i(j,t)a_i(j,t)}{\sum_{k=1}^{n}(w_i(k,t) + w_i(k,t)a_i(k,t))} \quad (4)$$

The notions of mind-set and *affinity* are what differentiate this model from the current literature. The motivation behind modifying the confidence according to a mind-set/opinion *affinity* is three-fold. Firstly, the specification of a mind-set allows for a parameter ($\mu$) which reflects the user preferences, predispositions or affiliations (e.g., left and right, globalisation and autarky). Secondly agents are able to recognise other agents with similar mind-sets and consequently influence and be influenced by the opinions of these agents with similar attitudes and tendencies (and even group together in high-confidence communities). Thirdly we wish to reflect the fact that there could be a difference between an agent's opinion and the agent's mind-set. Intuitively, it is expected that an initial opinion would be derived from the set of attitudes and preconceptions which constitute a mind-set. However, sufficiently strong influence from other individuals can 'persuade' an agent towards a completely different opinion. Moreover, it can even be the case that if this new opinion is highly regarded then it becomes part of the mind-set. This latter idea will be explored in future work.

**Complexity of the model**

As in similar models (see Section 5), due to its mathematical complexity, a computer simulation approach is required to analyse our model. As described in [10], the complexity of models such as that proposed in Section 2 lies in the non-linearity of the model which is due to the interdependency between the variables. That is, an opinion at time $t+1$ depends on the confidence at time $t$, which in turn depends on the *affinity* between mind-set and opinions at time $t-1$. Thus analytical results are difficult to obtain. Furthermore, the many possible configurations of initial values that the variables (i.e. initial opinion, initial confidence and mind-set) can take would lead to a combinatorial explotion with even a modest number of agents.

Due to the vast range of possible initial configurations (at $t = 1$) which could be used to instantiate the model, we adopt some initial assumptions which will help us extract some of its main properties (future work will be focused on the relaxation of these assumptions):

- Only one *issue* from one *topic* is discussed at a time;
- Agents are always truthful and can not refuse to exchange opinions;
- All the agents are acquainted with each other;
- An exchange implies an all-to-all participation of the agents and is always simultaneous;
- The number of agents is fixed from the start and remains unchanged.

## 3 Some definitions

Due to the considerably large number of configurations that can be formed, we approach the analysis by choosing (1) configurations which tell us something about real world scenarios and (2) configurations where fixed assumptions help the understanding of the opinion dynamics by simplifying the complexity of the model. Each configuration is examined using a computer simulation. The opinion dynamics and its relation to the observed configuration are analysed at *equilibrium*, i.e. when for all agents, the values of the variables no longer change with time.

Based on the characteristics of the model, we define (and in Section 4 analyse) the following agent profiles based on: (1) self-confidence, (2) confidence in other agents, (3) an agent's opinion fitting in its mind-set, and (4) opinions of other agents empathising with (fulfilling) an agent's mind-set (thus influencing its opinion).

**Self-confident** An agent $i$ is said to be self-confident when the confidence it has in itself is higher than the confidence in any other agent: $i \in \mathcal{N}, \forall j \in \mathcal{N} \backslash \{i\}, w_i(i,t) \gg w_i(j,t)$. As confidence changes with time so does the self-confidence. Self-confidence can be lost when an agent's opinion does not fit its mind-set. However, it can be reinforced as an agent's opinion is influenced to move towards its mind-set.

**Opinionated** Strong opinion holder determined not to change its opinion. Characterised by (1) high self-confidence at all times which is maintained (or even increased) by (2) its own opinion fulfilling its mind-set: $i \in \mathcal{N}, \forall j \in \mathcal{N} \backslash \{i\}, w_i(i,t) \gg w_i(j,t)$ and $o_i(t) = \mu_i$.

**Opinion leader** An agent becomes a leader of opinion when (1) it maintains the characteristics of an opinionated agent for a long period of time such that (2) other agents follow its opinion.

**Opinion follower** An agent following those opinions (1) which best fit its mind-set and/or (2) those agents in which it has most confidence.

**Paradigm-shifter** An agent that, from an equilibrium state, suddenly shifts its mind-set and opinion from an agreed opinion consensus to a different and unique opinion, and becomes an opinion leader.

# 4 Properties of the Model

## 4.1 Profiling opinion leaders

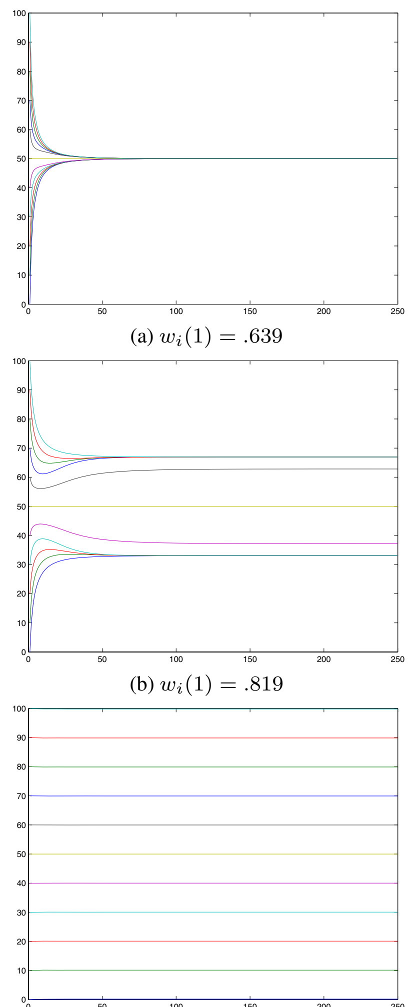
An opinion leader is specified as a highly self-confident agent with strong opinions (an opinionated agent). But, how much self-confidence is needed to be opinionated? We explore an all-opinionated configuration where no agent is expected to compromise in its opinion (i.e. no consensus is reached). Thus we set the agents' mind-sets equal to their initial opinions and their self-confidence is varied from a small self-confidence: $w_i(i,1) = 0.639$, to a large value: $w_i(i,1) = 0.999$.

Figure 1 shows the opinions of a group of 11 opinionated agents. In order to analyse the effect on the whole range of opinions, initial opinions (and mind-sets) are chosen equally spaced every ten units so that $o_1(1) = 0$, $o_2(1) = 10$, ..., $o_n(1) = 100$. Each figure shows a different value of self-confidence which is the same for each agent.

Figure 1a, corresponding to $w_i(i,1) = 0.639$, is close to the largest self-confidence value which will cause the opinions to reach a consensus in the mean opinion. From that point, as the self-confidence increases, the opinions fragment in clusters which slowly diverge from the centred consensus. Close to $w_i(i,1) = 0.999$ (see fig. 1c) there is no visible deviation from the initial opinion at all times. As each agent's mind-set is equal to its initial opinion the "self-affinity" $a_i(i,t)$ is increased each time step, thus increasing the self-confidence and maintaining the same opinion. Consequently it can be said that a self-confidence value of $w_i(i,1) = 0.999$ or larger is necessary to consider an agent as opinionated. This configuration shows that it is possible for opinionated agents to have different opinions and keep them over time without being influenced by other agents.

## 4.2 Profiling opinion followers

What makes an agent follow other agents? We start this analysis from the same high self-confidence configuration used to produce the all-opinionated result show in fig. 1c, but instead of giving each agent a different mind-set we now give all the agents the same value $\mu = 25$. As shown in fig. 1c, an initially high self-confidence suggests that an agent will preserve its opinion close to its initial value. However two properties of the model act against maintaining this state: (1) An agent $i$ builds confidence in another agent $j$ as $j$'s opinion satisfies $i$'s mind-set (i.e. taking $o_i(t)$ closer to $\mu_i$). Thus each time step increases the confidence of all agents in those with opinion closer to 25. (2) An agent $i$ modifies its opinion through a weighted average of all opinions and since in every time step more agents converge to $o = 25$ then $i$ is quickly pulled to $o_i = 25$.




(a) $w_i(1) = .639$

(b) $w_i(1) = .819$

(c) $w_i(1) = .999$

Figure 1: Self-confidence in opinionated agents: each line represents an agent's opinion evolution in time

As a result, and as shown in fig. 2a, after some time close to 500 time steps, this configuration develops into an opinion convergence at $o_i(500) = 25$ for all agents. High self-

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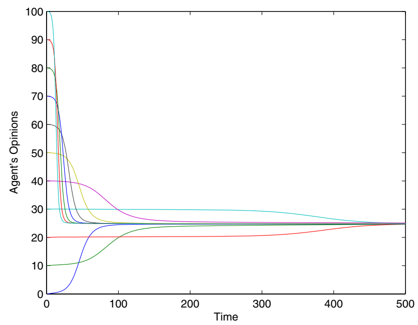
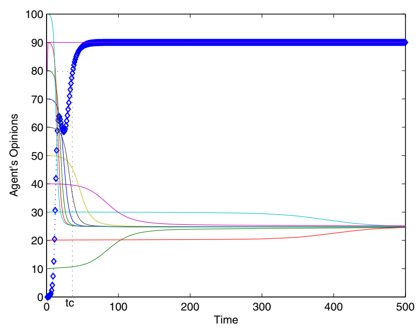
confidence causes each agent to keep as close as possible to its initial opinion for as long as possible. Slowly (and at different rates for different agents) the self-confidence is surpassed by confidence in other agents forcing the opinion to move towards $\mu$. Consequently the opinions are quickly attracted to $\mu$ by following (i.e. increasing the confidence in) other agents whose opinion is already close to $\mu$. This shows that self-confidence alone is not enough to be an opinion leader and that self-confident agents can also become opinion followers.




(a) Highly self-confident opinion followers




(b) Highly self-confident opinion followers with one opinionated agent with opinion fixed at $o_i = 90$

Figure 2: Opinion followers

Additionally, this behaviour provides one of the most significant characteristics of an opinion follower: at any given time, an agent $i$ will always follow the opinion(s) of that (those) other agent(s) in which the most confidence is appointed (including itself). However in subsequent exchanges, as long as there is at least another agent $j$ whose opinion is even slightly closer to $i$'s mind-set than anyone else's opinion, then $i$ will always tend to increase its confidence in $j$ and consequently, eventually follow $j$'s opinion (as long as $j$'s opinion remains close to $i$'s mind-set).

Following up this behaviour it can be observed that at an arbitrary time (e.g. $t_c$ in fig. 2b) an agent's opinion can be the closest opinion that matches its own mind-set. Fig. 2b shows the same configuration from fig. 2a with two additions: (1) an opinionated agent $p$ has been added at $o_p(t) = 90$, and (2) the agent $i$ (dashed, diamond-marked line) with initial opinion $o_i(1) = 0$ has been given a mind-set $\mu_i = 80$.

Initially agent $i$ follows those agents with initial opinion equal or closer to 80. As these agents diverge their opinions towards their mind-sets in $\mu = 25$, agent $i$ starts following only the opinion of the opinionated agent at 90. It would be expected that as $i$'s opinion approaches 80 its self-confidence would grow and its opinion would settle there. However confidence (thus self-confidence) is built slowly. The analysis of equation 4 evaluated at time $t_c + 1$ shows that the *relative* self-confidence would at most be "doubled" (i.e. if $a_i(i, t_c) = 1$, then the numerator of the term in equation 4 simplifies to $w_i(i, t_c) + w_i(i, t_c) \times 1 = 2 \times w_i(i, t_c)$). That, however, might not be significant relative to other values of $w_i(j, t_c)$.

Consequently, since at time $t_c$ the agent $i$ has more confidence in the opinionated agent than itself, $i$ becomes an opinion follower and agent $p$ opinion leader. Eventually $i$'s opinion is pulled out of its mind-set value by following the opinion leader.

## 4.3 The "lemming effect"

So far in our configurations we have only considered highly self-confident agents. We have seen that these agents can behave as opinion leaders or opinion followers. But what happens in the opinion formation dynamics of groups where no one has high self-confidence?

Consider a group of persuadable agents that are unknown to each other. They meet for the first time to discuss a certain issue. Also suppose that everyone in that group is open to listen to what others have to say. No one has a strong opinion and everyone is willing to follow someone else if they empathise with a given opinion. Moreover, this is a group where no agent has high confidence in another agent or even itself.

In such group we model each agent's initial confidence in another agent using a uniform random distribution. Similarly we apply the same distribution in modelling initial opinions and mind-sets characterising people from different backgrounds, with different preferences and priorities (thus no explicit consensus or fragmentation in opinions is initially observed).

Similarly to fig. 1a such an initial state quickly reaches a consensus where all opinions converge close to the *mean opinion value* of the initial opinion distribution. For all agents it can be inferred (from equation 1) that if it is the case that an agent has similar confidence in each other agent, then its opinion at $t = 2$ would approximately be the average of all the opinions. And since the initial opinions (at $t = 1$) are uniformly distributed over the interval $[a, b]$, where $a = 0$ and $b = 100$, then the opinion average would

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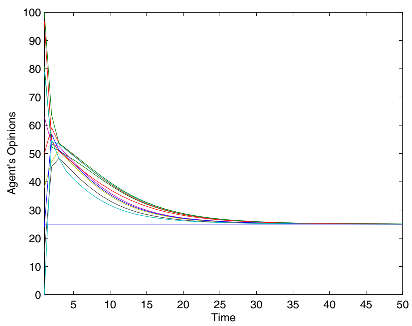
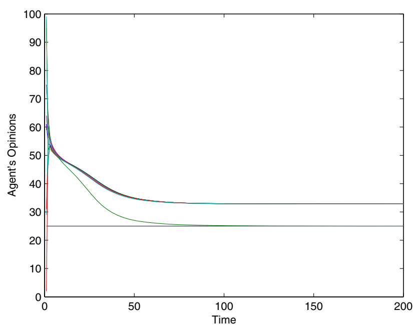
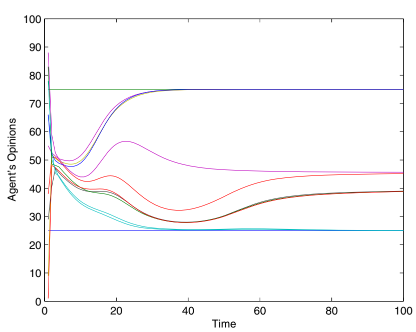
be close to the mean value of the distribution. At $t = 2$ the same effect is observed over a smaller opinion distribution interval around the previous mean value. Eventually, and closely after $t = 1$, all the opinions converge to a single value.




(a) Random configuration with one opinionated agent at $o_i(t) = 25$: Lemming effect




(b) Random configuration with one opinionated agent at $o_i(t) = 25$: No lemming effect




(c) Random configuration with two opinionated agents at $o_i(t) = 25$ and $o_j(t) = 75$: No lemming effect

Figure 3: Preventing the lemming effect

Consequently, it can be said that in a group of agents where: (1) opinions are diverse as well as backgrounds, tendencies and preferences (i.e. mind-sets), (2) where confidence is mutually and evenly distributed between all members (thus all opinions are equally important for everybody), and (3) no one has a strong or definite opinion, then a consensus will be reached around the mean opinion.

What would be the effect, in such a group, of one more agent: an opinionated agent $p$ with a strong opinion at $o_p(t) = 25$? As shown in fig. 3a, during the first time steps all the opinions approach the mean value of the opinion distribution. But eventually every agent whose mind-set is closer to agent *p's* opinion than the mean opinion shifts its opinion and confidence towards that of the opinionated agent. This behaviour influences the opinions of all the other agents. As long as these agents have some confidence in agent $p$ and/or in agents moving towards $p$ (and since *p's* opinion will not change), then those agents' opinions will also shift towards *p's* opinion. This *groupthink* behaviour of agents following the opinion of just one agent, against their own mind-set, just because they all follow each other and one (or some) of them follows the opinion of one agent is what we call the "lemming effect".[1]

How can the lemming effect be prevented? A first approach is shown in fig. 3b which is a different run from the same configuration that produced fig. 3a. In fig. 3b some agents reached a consensus in a mean opinion which better conforms with their mind-sets than that of $p$. But most importantly, the confidence between themselves increases sufficiently rapid such that the confidence in *p's* opinion has some influence on them but it cannot completely shift their opinions to it.

A second solution incorporates a second opinionated agent to the group. Figure 3c shows a single run of the opinion formation of such configuration. Firstly, it is observed that contrary to the effect observed in fig. 3a, the opinions do not converge to a consensus. Instead they fragment within the opinions of the two opinionated agents. These agents prevent the convergence of all opinions into one by influencing agents with similar tendencies to follow them. They become opinion leaders for some and opposing balancing forces for those other agents with mind-sets somewhere in between the two. Eventually those agents in the middle form clusters with agents with similar mind-sets.

This result suggests that the lemming effect can also be prevented by at least two opinionated agents with different opinions. And in such configurations the opinions of a community which has different mind-sets will not always converge to a consensus. This key characteristic of our model illustrates the strong influence of opinionated agents in the opinion dynamics.

## 4.4 Shifting paradigms

One of the main drawbacks of the lemming effect is that agents follow an opinion which "pleases" only a few

[1] The opinion (and myth) that "lemmings commit mass suicide by deliberately jumping off cliffs into the sea", being completely untrue but popularly believed, is a prime example of what we mean by the lemming effect.

agents (or even one). Agents follow a paradigm proposed by one strong opinion holder. This agent becomes an opinion leader in a group where none of the other agents holds a strong opinion and they hold equal confidence in each other. However, if at least one agent chooses to change its opinion outside the opinion formation dynamics then a paradigm shift is possible.

The first half of fig. 4 shows a single run of the same scenario observed in fig. 3a. The agents follow and adhere to the opinion of an opinionated agent ($o_p = 25$) which then becomes the opinion leader. Agents remain in this mainstream opinion until at time $t = 200$ an agent $i$ decides to change it's mind-set to $\mu_i = 75$ and becomes strongly opinionated (thus its opinion also shifts to $o_i = 75$.

The second half of the figure shows that as long as the group have some confidence in $i$ then they will consider shifting towards the new opinion. Those agents whose mind-sets empathise with $i$'s opinion will shift to $i$'s new paradigm by reinforcing the credibility in it. In response to this shift and due to the confidence that all the other agents have in the agents shifting, they will consider this new opinion. But if this opinion does not agree more with their mind-set (compared to their old opinion) then they will go back to the old paradigm. Thus, as history has proven, paradigm shifts are possible. It all starts with an agent willing to propose a new opinion and strongly holding it.

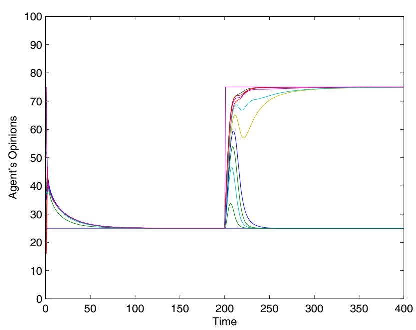



Figure 4: Paradigm shift

## 5 Related Work

A basic classification between opinion formation models has naturally been set as authors choose discrete (e.g. 0 or 1) or continuous (e.g. [0,1]) values to represent opinions. Many discrete opinion formation models have adapted Ising-based models of statistical mechanics. Galam [9] proposed an Ising-based, discrete, group decision making model and presented some results on group polarisation, social pressure and individual bias. Another Ising-type model was presented by Sznajd-Weron [17]. In this model an agent's opinion is influenced by the opinions of its nearest neighbours following a set of adjacency rules. This model, known as the Sznjad model, has been widely cited and many variations and applications have been studied in [16, 6, 14], and in the references given therein. More recently Wu and Huberman [18] presented another binary choice model which predicts the evolution of opinions by considering the topology of the social network.

Of more relevance to our model are the continuous opinion formation models. Some of the most discussed models are those of Deffuant et al. [3, 1, 13, 7, 15], Friedkin and Johnsen [8] and Hegselmann and Krause [10, 5, 12]. Deffuant [3] proposes a *bounded confidence* model where a pair of agents exchange opinions and influence each other only when their difference of opinion is below a certain threshold. Later in [2] Deffuant proposes the *relative agreement* model (as an extension to the *bounded confidence* model) where the influence of the agents is a function of their *uncertainty*.

Friedkin and Johnsen [8] build on models of social influence and use a *coefficient of social influence* which balances the influence exerted by an agent's initial opinion (formed by exogenous conditions) and the influence of other agent's opinions (endogenous influence). As a result the revision of $i$'s opinion at time $t + 1$ is bounded by the *coefficient of social influence* to the initial opinion and by a constant (in time) network of interpersonal influences to other agents' opinions.

Hegselmann and Krause [10], similarly to Deffuant, use a *confidence interval*[2] to constrain the exchange to *close-in-opinion* agents. However differently from Deffuant, but similarly to DeGroot [4] and Friedkin, they aggregate (using an arithmetic mean) opinions by giving a weight to each agent's opinion. Later, in [11] they also explore the use of geometric, power and random mean when aggregating opinions. In [10] it is observed that convergence of opinions exists but only within subgroups of agents with similar opinions (i.e. *polarisation* and *fragmentation*). An exception is when the *confidence interval* is large enough such that all opinions converge to the same value since all agents influence each other (i.e. *consensus*).

Our work does not make two assumptions which are present in most continuous models: (1) it is assumed that no external references are available thus its not possible to measure the value (usefulness) of opinions, and (2) it is assumed that agents assign a weight to the relation they hold with other agents and this weight either remains constant in time [4, 8] or changes equally for all [10]. We should note that, in his concluding remarks of [4], DeGroot recognised the limitations imposed by these assumptions.

[2]Note that our definition of *confidence* is similar to the conceptualisation of *weight* in [10], but is different from the idea of *confidence levels or intervals* used in the same paper.

By introducing the concept of mind-set we withdraw the first assumption by allowing agents to compare, follow and stick to the opinions which they consider an acceptable *reference or truth*. This valuation of opinions due to an external reference also allows the withdrawal of the second assumption. By knowing which opinions are more valuable (i.e. similar to their mind-set), agents are able to assign independent confidence values to individual agent's opinions (including its own).

## 6 Discussion and Further Work

We present an opinion formation model of dynamic confidence and individual mind-sets. This model allows the profiling and analysis of agents taking roles as opinion leaders and opinion followers.

It has been observed that strong opinion holders with strong self-confidence can easily become opinion leaders if there is at least one other agent which: (1) has strong confidence in that agent, and (2) empathises in its mind-set. This however could easily lead to a lemming effect where everyone in a group of persuadable agents follows the opinion of just one agent. Nevertheless this effect can be prevented by agents sharing a similar mind-set clustering together in an agreed opinion, and increasing each other confidence to counteract the influence of the opinion leader. A different approach suggests having another strong opinion holder which would counteract the effect of the first and give the agents an alternative opinion to follow. Opinionated agents with divergent opinions inhibit consensus.

Once agents have fallen in the lemming effect they will continue to follow the same paradigm. That is, unless at least one agent changes its mind-set and opinion to an alternative value, and increases its self-confidence giving the group an alternative paradigm to follow. Agents change their opinions as they listen to other sources which take them closer to what they tend to believe.

For the purpose of the analysis presented on this paper, only the opinion formation on one issue is analysed. However in future work the model will be extended to several issues. Furthermore, we will withdraw the assumption of a totally connected network to a topology where agents are only acquainted with a fraction of the network (e.g. random, small worlds and scale-free) and exchange is not necessarily simultaneous.

By considering different topologies we will be able to model agents with different degrees of connectivity, from highly interconnected mass-media agents to isolated individuals. We envisage that high connectivity could be added to the definition of opinion leader and groupthink would be more easily reached in fully connected groups. Under these conditions we are interested in finding how a group of regularly connected individuals sharing a common opinion can counteract the opinion of one highly connected agent.

## References


[1] G. Deffuant. Comparing extremism propagation patterns in continuous opinion models. *Journal of Artificial Societies and Social Simulation*, 9(3), 2006.

[2] G. Deffuant, F. Amblard, G. Weisbuch, and T. Faure. How can extremism prevail? a study based on the relative agreement interaction model. *Journal of Artificial Societies and Social Simulation*, 5(4), 2002.

[3] G. Deffuant, D. Neau, F. Amblard, and G. Weisbuch. Mixing beliefs among interacting agents. *Advances in Complex Systems*, 3(1-4):87–98, 2000.

[4] M. H. DeGroot. Reaching a consensus. *Journal of the American Statistical Association*, 69(345):118–121, Mar. 1974.

[5] S. Fortunato. Damage spreading and opinion dynamics on scale-free networks. *Physica A: Statistical and Theoretical Physics*, 348:683–690, Mar. 2005.

[6] S. Fortunato. The Sznajd consensus model with continuous opinions. *International Journal of Modern Physics C*, 16(1):17–24, 2005.

[7] S. Fortunato and D. Stauffer. *Computer Simulations of Opinions and Their Reactions to Extreme Events*, chapter 11. The Frontiers Collection. Springer-Verlag Berlin, 2006.

[8] N. E. Friedkin and E. C. Johnsen. Social influence and opinions. *Journal of Mathematical Sociology*, 15:193–205, 1990.

[9] S. Galam. Rational group decision making: A random field Ising model at t = 0. *Physica A: Statistical and Theoretical Physics*, 238(1-4):66–80, Apr. 1997.

[10] R. Hegselmann and U. Krause. Opinion dynamics and bounded confidence: models, analysis and simulation. *Journal of Artificial Societies and Social Simulation*, 5(3), 2002.

[11] R. Hegselmann and U. Krause. Opinion dynamics driven by various ways of averaging. *Computational Economics*, 25(4):381–405, 2005.

[12] J. Lorenz. Consensus strikes back in the Hegselmann-Krause model of continuous opinion dynamics under bounded confidence. *Journal of Artificial Societies and Social Simulation*, 9(1):–, Jan. 2006.

[13] G. Mckeown and N. Sheehy. Mass media and polarisation processes in the bounded confidence model of opinion dynamics. *Journal of Artificial Societies and Social Simulation*, 9(1):–, Jan. 2006.

[14] D. Stauffer. Monte carlo simulations of Sznajd models. *Journal of Artificial Societies and Social Simulation*, 5(1), 2001.

[15] D. Stauffer, A. Sousa, and C. Schulze. Discretized opinion dynamics of the Deffuant model on scale-free networks. *Journal of Artificial Societies and Social Simulation*, 7(3), 2004.

[16] K. Sznajd-Weron. Sznajd model and its applications. *Acta Physica Polonica B*, 36(8):2537, 2005.

[17] K. Sznajd-Weron and J. Sznajd. Opinion evolution in closed community. *International Journal of Modern Physics C*, 11(6):1157–1165, 2000.

[18] F. Wu and B. A. Huberman. Social structure and opinion formation. http://arxiv.org/abs/cond-mat/0407252, 2004.



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