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Modeling self-perception agents in an opinion dynamics propagation society

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Abstract

In previous continuous opinion dynamics models based on bounded confidence assumptions, individuals can only influence each other's opinions when those opinions are sufficiently close; subsequently, agents construct their self-opinions using opinions collected from other agents. All of these models lack the element of an agent's inner self-attitude. In this paper we describe our proposal for a self-perception model in which agents are aware of differences between their attitudes and expressed opinions on specific issues. Our agents are based on a mix of self-perception and cognitive dissonance theory that allows them to self-adjust discomfort caused by inconsistencies between inner attitudes and expressed opinions. Results from a series of simulation experiments indicate that our model captures the gap between inner attitude and external opinion in explaining the private acceptance/public conformity phenomenon. We conclude with a demonstration of how our proposed model can be used in sociological studies of pluralistic ignorance.

Keywords

Self-perception, opinion dynamics, multi-agent-based simulation, theory of reasoned action, cognitive dissonance theory, public compliance, private acceptance

1. Introduction

The process of exchanging opinions with others is an important daily life activity, from the lowest level of choosing social events to high-level negotiations between nations on economic policy.[1–8] When exchanging opinions, we tend to believe that not only can our thoughts influence others, but also that we are open to having our ideas and opinions affected by other individuals as well as overall public opinion.[3–6,9,10] New forms of media (especially the Internet) support the consumption of information and provide platforms for the public sharing of reactions in response to ideas. Researchers are currently addressing new trends in societal influences and public opinion formation constructed and disseminated via electronic transmission formats.[11–14] Specifically, a growing number of social scientists are studying ways that information is dispersed.[1,2,6,11–14] Examples include studies of mass protest activities supported by social and network media, such as Facebook and Twitter, and analyses of discourses used by different political parties based on individual opinion data.[6,11,13–15]

Many of these researchers have used agent-based artificial societies and simulations to address the topic of ''dynamic opinion propagation''.[3,6,12,13,16–19] The most frequently used models of opinion dynamics are the bounded confidence (BC)[4] and Hegselmann–Krause (HK)[3] models. Based on the BC model, the HK model has the additional uncertainty parameter ε.[3,16] In both models, dynamic opinion operating rules are based on the principles of whatever discipline is being studied—physics, mathematics, computer science, psychology, or philosophy, among others.[3,13] Agents in these models adjust their self-opinions upon hearing the opinions of other agents. According to the BC concept, an agent only exchanges opinions with agents that have similar opinions.[3,4,6] The problem is that individual opinion is a simple variable representing the collective value of opinions among interacting agents. For example, after interacting with two individuals named Allan and Bob, the opinion value of a third individual named John is equal to the collective value of Allan's and Bob's opinions. In other words, one's

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opinion represents the integrated values of ideas from friends, family members, and other sources such as the media. In real-world scenarios, individuals also deal with input in the form of internal ideas and self-attitudes. Many researchers in the fields of sociology and psychology have observed inconsistencies between individuals' inner attitudes and expressed opinions,[5,20–25] with checks and balances coming in the form of job or social pressure and public opinion, among others.[5,20,22]

Sociologists have noted that when people express their opinions under normative informational social influences,[5,12,24,25] they are likely to feel a mix of private acceptance and public conformity[26–28] — that is, a gap between inner attitude and the explicit expression of an opinion. According to experimental results reported by Asch,[5,23] individuals often agree with others' opinions due to a desire for security within groups typically consisting of individuals of a similar age, culture, religion, or educational status. A frequent outcome is ''groupthink,'' defined as thought patterns characterized by self-deception, the forced manufacturing of consent, and a conformity to group values and ethics that ignores realistic appraisals of other courses of action. Individuals tend to move toward their self-attitudes once the pressure of social norms and public opinion abates.[5] According to Bem's self-perception theory,[21,22] individuals deduce their self-attitudes and feelings by observing their own behaviors and contexts, especially when their attitudes and feelings occur under ambiguous conditions. According to Bem's theory, individuals only deduce their self-attitudes and feelings based on their behaviors when they do not fully understand their true feelings; if they understand their true attitudes, there is no need to observe their behaviors.[29,30] However, since attitudes tend toward ambiguity, most individuals need to observe their behaviors to clarify their own attitudes.[31–34]

Based on this background, we believe that individual opinions and behaviors represent much more than the integrated value of other's opinions, and that inherent attitudes must also be taken into consideration. One of our primary goals is to add the element of inner attitude to an opinion dynamics agent model. We believe that if agents can be created with self-perception capabilities (i.e., the ability to perceive, distinguish, and balance conflicts between behaviors and attitudes), then multi-agent-based simulations of social phenomena will have greater explanatory power. Toward this goal we have constructed a self-perception agent model with the characteristics of private acceptance and public conformity. In this paper we will use the social psychology terms ''attitude'' (an individual's internal evaluation of events, which others cannot directly observe) and ''opinion'' (an individual's expression of events in the form of external behaviors such as utterances, emotions, and body language) to respectively represent an agent's private and expressed thoughts. To explore the potential micro-level impacts of informational and normative social influences, we feel that a single opinion attribute within a traditional opinion dynamics model must be divided into attitude and opinion attributes in order to represent richer and more realistic collective opinion dynamics. We conducted a simulation experiment to verify consistency between our proposed model and previous continuous opinion dynamics models based on the BC assumption, and to confirm that group opinions and attitudes have different macro-level dynamics and outcomes. After reviewing the basic properties of our simulation model and discussing our sensitivity analyses of micro-level factors, we will discuss pluralistic ignorance (an important topic in contemporary sociology) to demonstrate our proposed model's value and potential applications.

2. Background

2.1 Group conformity

According to the BC assumption, individuals who are unsure of or unfamiliar with issues tend to adopt or be strongly influenced by opinions expressed by others who share a common culture or other similarities.[35] There are problems with this approach: as Asch[5,23] famously showed, in a situation where the answer to a certain question is very clear, if one-third of the test takers in a room observe their fellow test takers choosing the wrong answer, they are very likely to choose the wrong answer regardless of whether or not they know it is wrong. Asch concluded that the test takers willingly chose the wrong answer in order to maintain conformity, gain acceptance, and avoid rejection by other group members — an example of normative social influence. Support for Asch's findings includes the reasoned action theory of Ajzen and Fishbein,[20] who showed that both private attitudes and subjective norms must be taken into consideration when predicting an individual's behavior in terms of expressing opinions. They also observed that after taking into account the judgments of others surrounding them, individuals frequently express opinions and behaviors that differ (sometimes to a large extent) from those they would normally express—in other words, private attitudes do not necessarily equal expressed opinions or behaviors.

The influences of collective beliefs on expressed opinions can be significant even when individuals do not change their private opinions.[12,36] According to the concept of pluralistic ignorance — said to occur when members of a group are affected by strong normative social influences — those who disagree or who are hesitant to agree with mainstream views on specific issues may mistakenly perceive themselves as the only non-conformists in a group, and either choose or feel compelled to publicly proclaim allegiance to group opinions without knowing how many others also disagree with the mainstream view. In some cases the opinions of an entire group may change

considerably if a single non-conformist expresses his or her actual opinion, perhaps leading to a complete rejection of the previously dominant opinion. However, in cases where the original mainstream opinion prevails despite disagreement on the part of one or more individuals, opinion dynamics models based on the BC assumption fail to explain the pluralistic ignorance phenomenon, since it would indicate that non-conformists do not have to worry about their opinions clashing with others. Further, such a scenario would decrease the power of an opinion dynamics model to explain why a group might doubt or overturn its previous opinions in response to a minority view.

2.2 Cognitive dissonance and self-perception theory

According to Festinger's cognitive dissonance theory,[37] individuals whose private attitudes are inconsistent with their behaviors suffer from unpleasant psychological states and cognitive dissonance. To avoid these problems, humans often alter their attitudes to match the current direction of behaviors expressed by those surrounding them, and support behaviors that in other circumstances they would consider contradictory. Individuals rarely change their expressed behaviors for purposes of mitigating cognitive dissonance, since changing one's behaviors is equivalent to publicly acknowledging mistakes — a situation that for many is even less acceptable. When publicly reacting to normative social influences, or when stating opinions that are very different from their own private attitudes due to a lack of external justification or a desire to avoid punishment, individuals may seek internal justification, change their private attitudes, and/or move in the direction of public opinion in order to narrow the cognitive distance between expressed behaviors and private attitudes, as well as to decrease cognitive dissonance and persuade themselves to believe in the opinions they utter.

Bem's self-perception theory offers an explanation for the connection between behaviors and attitudes.[21,22,38] He believes that when individuals are asked to describe their attitudes regarding an event, they initially recall prior behaviors related to the event, and use those memories to infer current attitudes. In other words, Bem believes that attitude emerges after the behavioral fact — it is the tool that makes the fact meaningful, rather than a guide for subsequent action. Using personal attitudes to analyze this theory, Bem argues that individuals believe that their behaviors are true expressions of their inner attitudes in the absence of external pressure; however, when obvious external pressure exists, those same individuals believe that their behaviors are dictated by external pressures and environmental factors rather than internal motivation. If we use personal motivation to analyze this theory, certain activities that offer the potential for large rewards encourage individuals to attribute their behaviors to external reasons rather than their true attitudes, while activities with no potential for anything beyond small rewards allow individuals to attribute their behaviors to internal reasons or true attitudes.

Cognitive disorder theory emphasizes the importance of attitude in the inherent tendencies of individuals. When the behaviors of individuals contradict their attitudes, they are said to be in ''uncomfortable disorder''.[37] To alleviate this sense of discomfort, they must revise their attitudes to correspond with their behaviors. Compare this to the above-described assertion by self-perception theorists that people often enact behaviors that purposefully reflect their external environments — that is, people's behaviors only reflect their true attitudes when there are no significant external incentives. Although these two theories start from different points, their results are the same: the greater the incentive (in the form of pressure, reward, or punishment), the weaker the true feelings for an individual's behavior. Social psychologists generally do not view these theories as contradictory: when an individual's outward behaviors are clearly understood, cognitive disorder theory may be a better explanatory tool, but when that is not the case, then self-perception theory may be more appropriate.

2.3 Opinion dynamics model

In most multi-agent-based dynamic opinion models, opinions are encoded as real numbers within a range, and all possible opinion values are organized into sets known as opinion spaces. Some opinion spaces are continuous (e.g., [0, 1]), while others are discrete (e.g., $\{-1, +1\}$). Nodes are social network agents; two agents are said to be linked if they share an edge, which allows them to exchange opinions. When initializing a model, the system assigns each agent a random number representing its initial opinion. The distribution of these opinions will reflect some form of probability, such as a normal distribution. This type of model supports observations of the evolution of opinion dynamics among individuals and groups in terms of consistency or dispersal, and the insertion of different parameters to trace their impacts on opinion evolution.

As stated earlier, the BC model asserts that individuals only exchange opinions with others who have the same opinions. Accordingly, opinion exchange only occurs when the distance between two agents' opinions is shorter than a certain range. In the HK model,[3] opinions are designated as real numbers in the interval [0, 1]. The most important parameter is uncertainty ε. At the beginning of a simulation, all agents' ε values are the same (i.e., uniform level of confidence). During each opinion exchange iteration, a randomly selected agent communicates with agents whose opinions differ from those of the selected agent within the ε value, thus signifying degree of compatibility. The randomly selected agent collects opinions from compatible agents, and its new opinion represents the average

Table 1. Agent attributes.

Attribute	Type	Range	Description
Op	Real	[0, 1]	An agent's expressed opinion on a specific issue as revealed by external behaviors.
Att	Real	[0, 1]	An agent's private views on a specific issue.
unc	Real	[0, 1]	Uncertainty (default value = 0.6).
pub_thr	Real	[0, 1]	A threshold value. When public opinion strength exceeds *pub_thr*, an agent will chose public compliance (default value = 0.6).
pri_thr	Real	[0, 1]	A threshold value. When public opinion strength remains below *pri_thr*, an agent will not change its opinion. No default value.

of those collected opinions — a Monte Carlo algorithm.[39] Hegselmann and Krause[3] manipulated ε in order to view all possible results and to establish asymmetrical cases in which agents are assigned two ε values (ε_l and ε_r) to represent two levels of uncertainty. Such cases are meant to give the model more explanatory power for real-world social situations. Deffuant et al. [16] used the HK model as a starting point to propose the D model for studying cases of extremist ideas that gain strength under identifiable circumstances. Both the D and HK models are based on the BC concept, with opinion space defined as [–1, + 1]. There are at least three distinct differences between the two: in the D model (a) the influence of views is bidirectional when two agents exchange opinions, (b) the value of the ε uncertainty parameter changes as opinions are exchanged, and (c) two kinds of agents, extremists and moderates, are embedded in the simulation space for purposes of understanding the spread of extremist views.

Since the HK model lacks the structure of a social network, all compatible agents in that model engage in opinion exchanges. Due to its flexibility, the HK model is preferred by many opinion dynamics researchers, including those wanting to add the factors of dynamic social networks,[13,14] multiple topics,[8] mass media,[1] and the spread of extreme opinions.[2] For this study we borrowed from both the BC and HK models to build our self-perception agent model.

3. Self-perception agents in opinion dynamics simulations

3.1 Self-perception agent model

We designed our self-perception agent model to support efforts by agents to be aware of differences between their attitudes and expressed opinions on specific issues. It is based on a combination of existing opinion dynamics agent[3] models, plus findings from the social psychology literature on public conformity and private acceptance,[5,24,25] cognitive dissonance,[35] and self-perception.[21,22,38] The private attitude and uncertainty parameters in our model represent the personal characteristics of agents. Our self-perception agents are capable of an internal debate process that produces discomfort in the presence of attitudinal and behavioral inconsistencies. In other words, we have attempted to add cognitive dissonance and self-perception theory to the self-interpretation process to sharply reduce the discomfort caused by such inconsistencies. Private agent attributes expressed as real numbers between 0 and 1 are shown in Table 1: opinion (*op*), attitude (*att*), uncertainty (*unc*), public compliance threshold (*pub_thr*), and private acceptance threshold (*pri_thr*). As stated, *att* and *op* respectively represent an agent's private views on a specific topic and its opinion as expressed through external behaviors. The narrower the gap between the values of these attributes, the more positive an agent's opinion will be on a specific issue. The *unc* attribute represents the degree of uncertainty that an agent feels about a specific issue: the higher the *unc* value, the less positive the agent's opinion, and the more likely the agent will be influenced by or adopt an outside opinion.

3.2 Dynamic opinion exchange simulation process

Our public opinion definition supports sufficient levels of homogeneity (i.e., consolidation to a limited number of opinion groups) so that normative social influences may emerge — influences that strongly encourage some members of a group to follow the majority opinion. The more concentrated a group's opinions or the greater the number of members in a group, the more pressure individual agents will feel to follow public opinion. We will describe how public opinion magnitude is calculated when we discuss the agent opinion updating process. All results represent average values for 50 runs. Simulation system parameters are listed in Table 2.

The underlying social network of our model consists of a two-dimensional $CEL\_AUT\_LENGTH^2$ cellular automaton with periodic boundary conditions. Each cell represents one agent, meaning that each automaton consists of $CEL\_AUT\_LENGTH^2$ agents. During each time step, all agents go through an opinion updating process in which opinions are exchanged with their surrounding neighbors. A group opinion update is defined as the execution of opinion updates by all agents during a single time step. The process consists of two steps:

Box 1.

```
Step 1: comment neighbor clustering
        Individual agents use a K-means clustering algorithm [40] to partition their
        neighbors into g group according to the degree of opinion similarity.
Step 2: if g ≤ NSI_THR then
           comment Public opinion is formed.
           if agent.unc > UNC_THR then
              comment Agent has height uncertainty.
              Assign the agent's opinion and attitude as the center of the opinion group having the most
              members--that is, equivalent to the average member opinion value of the largest group.
           else {* agent.unc > UNC_THR *}
              comments Agent detects inconsistencies between its attitude and opinion.
              Step 2a: Based on each group's center (i.e., group or public opinion equivalent), locate
                       the group opinion that is closest to the individual agent's opinion.
              Step 2b: Use three factors to calculate public opinion strength:
                       (1) the number of individuals in an opinion group (the higher the number, the
                           stronger the opinion);
                       (2) group opinion homogeneity (greater consistency indicates more strongly held
                           opinions); and
                       (3) discrepancies between agent attitude and public opinion (more discrepancies
                           indicate stronger public opinion).
              Step 2c: As part of the internal debate process, determine whether or not the agent follows
                       the group's opinion.
           end if
        else {* g > NSI_THR *}
           comment Public opinion is not formed.
           Assign an agent's opinion as its agent attitude, sum its opinion plus all compatible opinion
           values from its eight surrounding neighbors, and calculate an average opinion value representing
           both its opinion and attitude.
        end if
```

Table 2. System parameters.

Parameter	Type	Range	Description
NSI_THR	Integer	> = 0	Normative social influence threshold (default value = 2).
UNC_THR	Real	[0,1]	Attitude-less agent threshold (default value = 0.8).
CEL_AUT_LENGTH	Integer	> = 0	Number of cells of one cellular automata dimension (default value = 24).

In Step 1, individual agents use a *K*-means clustering algorithm[40] to partition their neighbors into *K* groups. This algorithm requires the assignment of a group number *K* prior to execution; for our experiments we assigned values of 1, 2, 3, 4, and 5, and then applied a square error function (Equation (1)) to evaluate the grouping results following algorithm execution. We interpreted smaller *squ_error* values as indicating more appropriate grouping results, with the lowest *squ_error* representing the most appropriate group number for the surrounding neighbors of any agent:

$$squ\_error = \sum_{i=1}^{k} \sum_{\text{agent } j \in \text{ group } i} \sum (\text{agent } j.op - \mu_i)^2 \quad \text{where } \mu_i \text{ is the group center of the opinion of group } i. \tag{1}$$

In Step 2, the agent determines the presence or absence of a normative social influence. We assumed that when the opinions of any agent's neighbors exceeded the *NSI_THR* threshold, a group opinion had not yet been formed, and the agent was not yet subject to peer pressure. A BC assumption is reasonable in such situations: the greater an agent's certainty on a specific issue, the less likely the agent will refer to its neighbors' opinions and vice versa. When one or several opinion groups consisting of an agent's neighbors are formed ($\leq NSI\_THR$), agents who insist on retaining their own ideas risk rejection. Agents with very high degrees of uncertainty (i.e., agent.*unc* > *UNC_THR*) are likely to follow the largest group's opinion. When expressing opinions, agents with low degrees of uncertainly must consider their own preferences versus group norms, select a group opinion that is closest to their

own, and express corresponding behaviors after calculating the strength of that group's opinion. Agents can disregard insufficiently strong opinions.

Initially, three kinds of opinion strength values must be calculated as part of step 2b:

(1) $f_a(x$: the number of individuals in an opinion group$) = \begin{cases} 0.1x - 0.1 & 1 \le x < 2 \\ 0.2x - 0.3 & 2 \le x < 3 \\ 0.5x - 1.2 & 3 \le x < 4 \\ 0.2x & 4 \le x \le 5 \end{cases}$;

(2) $f_b(x$: group opinion homogeneity$) = 1/(1 + e^{24x-6})$; and

(3) $f_c(x$: discrepancies between agent attitude and public opinion$) = 1/(1 + e^{-12x+6})$.

Lastly, public opinion strength (*op_str*) is calculated as $op\_str = (f_a + f_b + f_c)/3$.

Calculating the individual strengths of these factors (expressed as real numbers between 0 and 1) followed by average value calculations produces a strength of public opinion value, *op_str*, also a real number between 0 and 1. Pressure to conform to a group opinion increases as *op_str* approaches 1. After calculating *op_str*, agents determine whether or not they should comply based on their *unc* values, and decide whether or not they truly agree with public opinion.

In step 2c, we suggest using a public opinion spectrum when executing the internal debate process. We used two thresholds (designated *th1* and *th2*) to divide the public opinion spectrum into three categories:

Box 2.

```
Step 1: comment default value of pub_thr
        def_val_pub_thr ← 0.6
Step 2: comment Calculate th1 and th2
        th1 ← 1 − agent.unc
Step 3: if (th1 < def_val_pub_thr) then
           th2 ← def_val_pub_thr
        else
           th2 ← th1
        end if
Step 4: comment Internal debate process
        switch (public opinion strength op_str)
              when op_str < th1 do
                   op_str is too weak for agents to follow their respective groups in terms of either
                   attitude or opinion.
              end when
              when th1 ≤ op_sr < th2 do
                   comment Private acceptance
                   (a) The strength of public opinion is considered moderate. According to cognitive
                   dissonance theory [37], for those agents with smaller uncertainty values (unc),
                   public opinion is sufficiently strong for them to go along with public opinion,
                   thus demonstrating inconsistency between their inner attitudes and expressed
                   opinions. To resolve the imbalance, agents change their attitudes to match
                   expressed opinions/behaviors in order to mitigate inconsistency.
                   (b) Regarding agents with larger unc values, self-perception theory states that the
                   strength of public opinion in Case 2 is sufficient to induce those agents to follow
                   public opinion. However, the strength of public opinion is still insufficient for
                   making agents with high uncertainty values to be aware of public opinion pressure,
                   therefore they continue to believe that their decision to follow public opinion is
                   based on their internal attitude.
                   (c) Accordingly, the result is the same regardless of which theory is adopted-that is,
                   agent attitudes and opinions will eventually be consistent with public opinion in
                   this case. This is an example of the social psychology concept of private acceptance.
              end when
              when th2 ≤ op_str do
                   comment Public conformity
                   In this case, public opinion strength is too big. Both cognitive dissonance and
                   self-perception theory assert that agents have sufficient external reasons to conform
                   to public opinion in order to ensure group inclusion, yet they are aware that their
                   decisions do not represent their true attitudes. This is an example of the social
                   psychology concept of public conformity.
              end when
        end switch
```

4. Results and discussion

4.1 Differences between opinion and attitude

We executed opinion dynamic simulations to look at the kernel problem of differences/gaps between opinions and attitudes. Initial parameters were set as follows.

NSI_THR = 2; when less than 2, an agent feels normative social influence pressure.

UNC_THR = 0.8; when greater than 0.8, an agent has no self-attitude, and its attitude and opinion will be the same as that of its largest surrounding group.

pub_thr = 0.6; when greater than 0.6, an agent will choose public compliance, but without changing its own attitude.

Simulations were run with 2500 agents (25×25 cells) according to the algorithm described in Section 3.2; all agent *unc* values were set at 0.7. Different types of agent opinions are marked in different colors in Figures 1 and 2, and time and opinion distributions are shown in Figure 3. The figure data indicate obvious differences in evolutionary results for attitude and opinion. According to the standard deviation data shown in Figure 4, the speed of opinion and attitude evolution trends gradually declined and stabilized, with attitude SD approximately 50 times larger than that of opinion. When SD is used to quantify degree of consistency, the opinion centralization trend is clearly more distinct compared to that for attitude.

Our results indicate a scattered opinion distribution during the early simulation stages, with the number of opinion groups surrounding each agent exceeding 2. Opinions became more consistent as opinion dynamics evolution progressed, meaning that the number of opinion groups decreased. There was a surge in normative social influence when that number fell below 2 (Figures 5–7). Almost all agents were surrounded by multiple opinion groups during early evolutionary stages (a situation described as ''turbulent opinion distribution''), with all agents expressing their true attitudes. Opinions became more concentrated after several rounds of opinion exchanges, indicating the formation of normative social inferences/public opinions. Agents became more concerned about assessing public opinions before expressing their own, and showed tendencies to move toward the closest opinion group. Agents chose public compliance when public opinion pressure reached a certain level, but without changing their attitudes. That pressure was the primary reason for differences between attitudes and opinions.

4.2 Pluralistic Ignorance

Pluralistic ignorance refers to a situation where a majority of group members privately reject a norm, but assume incorrectly that most others accept it[41] — that is, ''no one believes it, but everyone thinks that everyone else believes it.''[42] Lack of public opposition thus perpetuates a norm that may in fact be rejected by the majority. In pluralistic ignorance scenarios, individuals privately disdain but publicly support a norm or belief, whereas a false consensus effect causes people to wrongly assume that most individuals think the same way they do (even though the majority of others do not), and therefore tend to openly express their disagreement.

Real-world pluralistic ignorance is broken when some individuals dare to express their true attitudes.[43] For example, employees may complain about their employer's policies for a long time, but not take any action. When they do start to express their ideas, the accumulation of grievances can produce great strength. Another example is a car accident in which all witnesses stand to the side without taking action—this is more of an example of pluralistic ignorance than indifference when they are uncertain about how to act/react. Such a situation likely changes when a single individual (known as the ''expresser'') takes action, giving the majority the courage to express their true attitudes based on their agreement with the pioneer's opinion.

To simulate pluralistic ignorance, we set the majority of attitudes at 0.1, opinions at 0.9, and the uncertainty parameter *unc* value at medium-high. Only one agent held a firm opinion (0.1 attitude and opinion values and low *unc* value). As shown in Figure 8, it took very little time for the group opinion to completely change. According to these results, even when the majority of individuals expressed their own attitudes, they still experienced medium-high degrees of uncertainty. When agents observed their surrounding agents' opinions, they discovered large differences between those opinions and their own attitudes. According to normative social values, agents should have chosen public compliance in this scenario, but the appearance of a strong pioneer helped others express their true attitudes. The power of the pioneer's idea slowly permeated the entire group, leading to a dramatic change in all agent opinions—in other words, pluralistic ignorance was broken. According to these results, our proposed self-perception agent model is capable of accurately simulating the phenomenon of a small number of individuals influencing the opinions of the majority.

5. Conclusion

In this paper we described our proposed self-perception agent model for exploring collective opinion and attitude dynamics. Based on a BC assumption, our model combines normative social influences with a continuous opinion dynamics model. According to our simulation results, opinion dynamics under normative social influences result in a gap between attitudes and opinions. If a small number of agents with new self-perceptions are added to a group in which a consensus has already been achieved, and if the new agents' initial opinions and attitudes are randomly

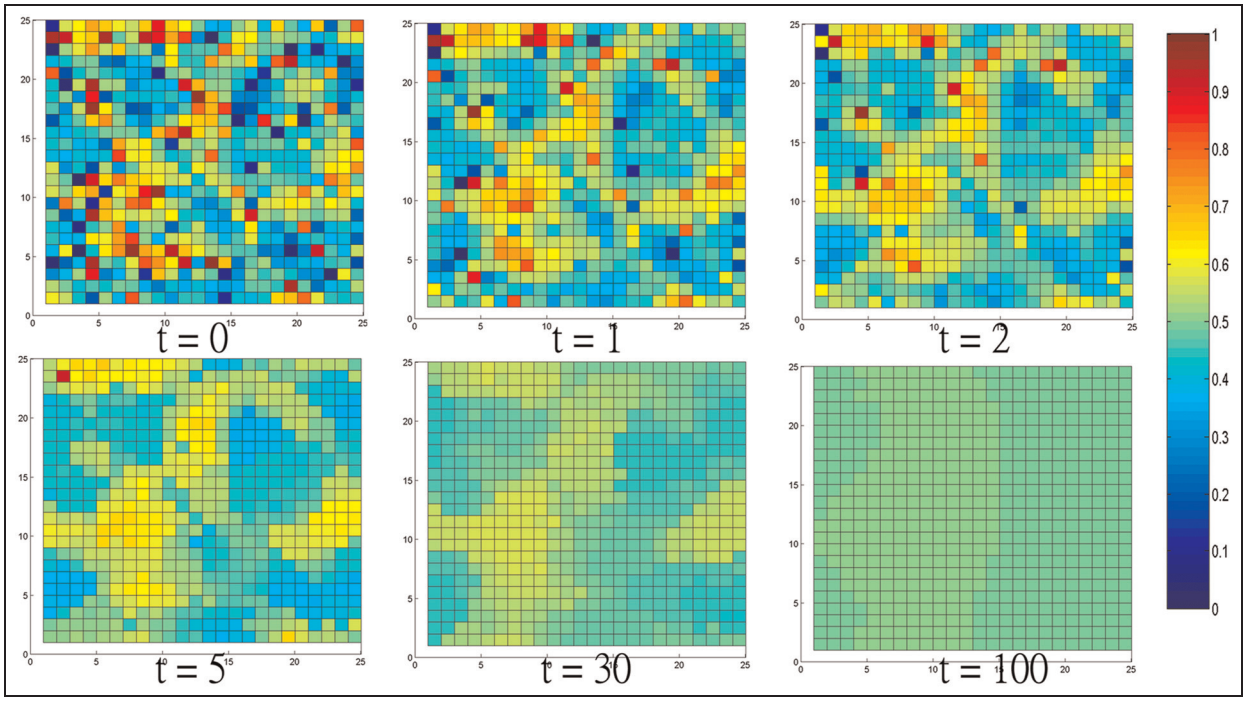

Figure 1. Evolution of self-perception agent opinion dynamics in cellular automata.

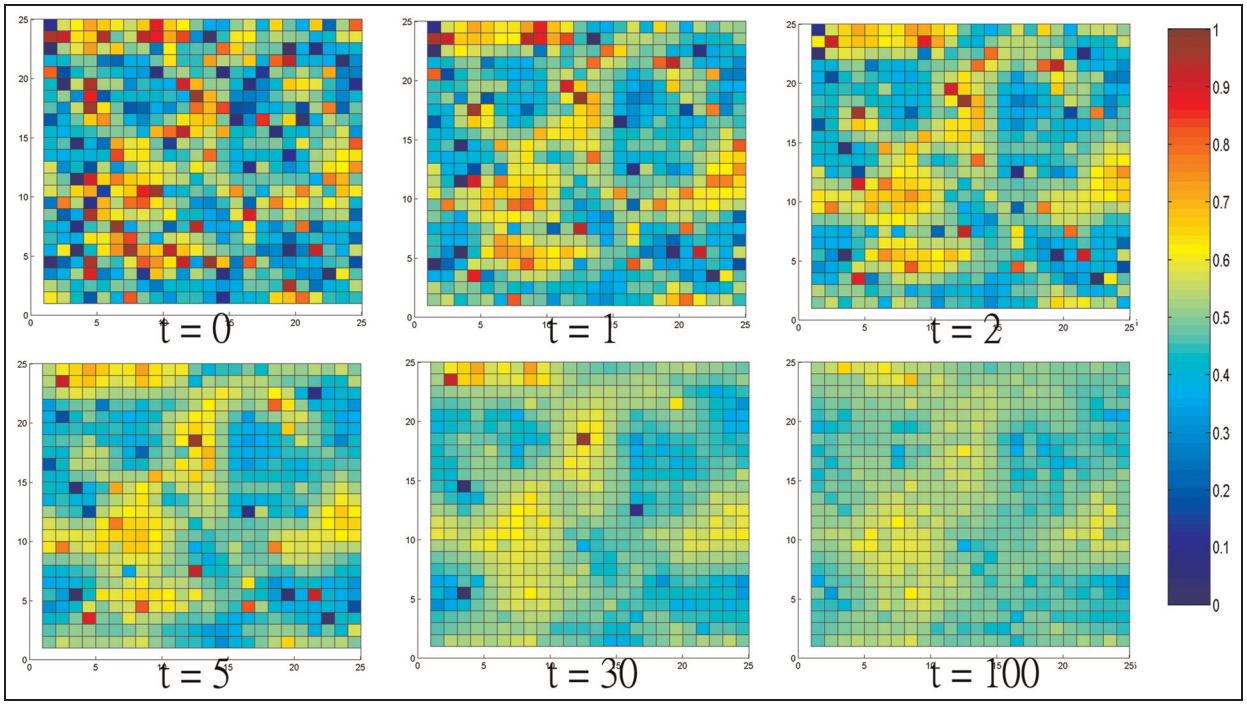

Figure 2. Evolution of self-perception agent attitude dynamics in cellular automata.

distributed, most of them will choose public compliance due to the magnitude of public opinion. Consequently, all group members will express identical opinions even though their attitudes may not be identical. We found that attitudes became more scattered as the process was repeated, whether or not opinion homogeneity remained

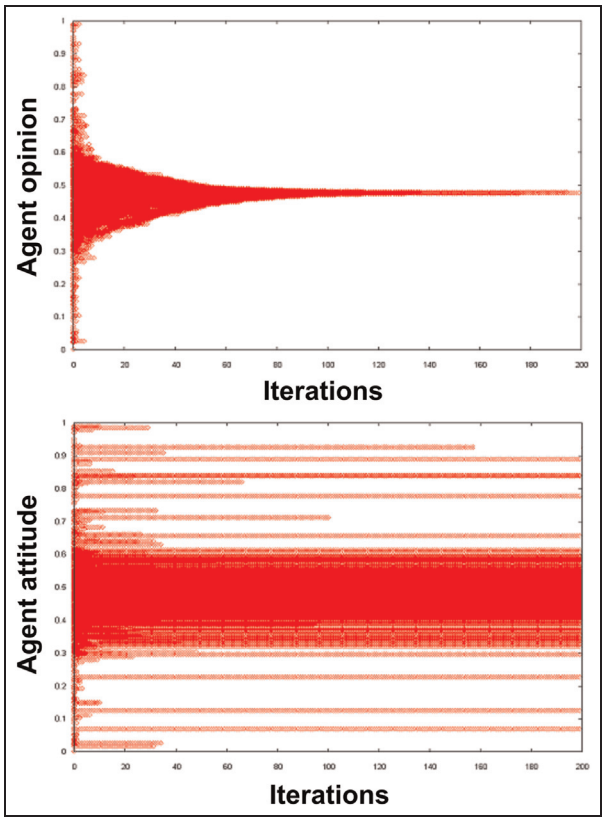

Figure 3. Opinion and attitude distributions.

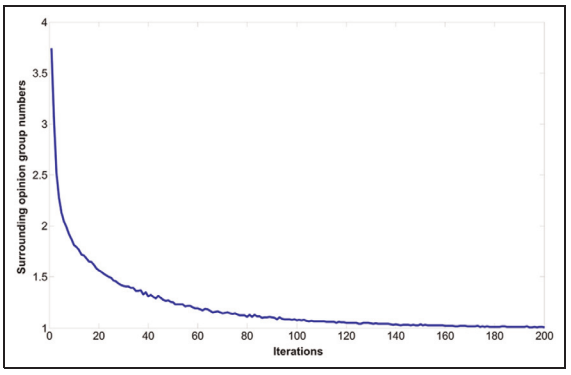

Figure 5. Average numbers of surrounding opinion groups.

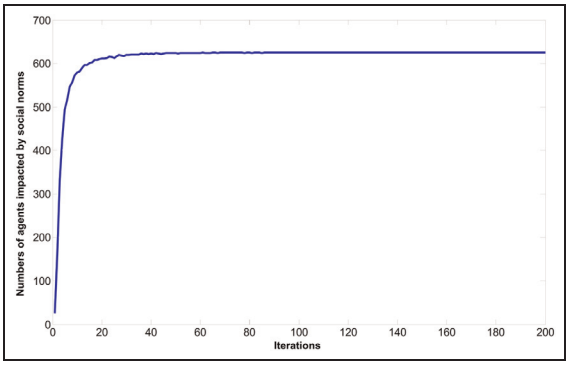

Figure 6. Numbers of agents impacted by social norms.

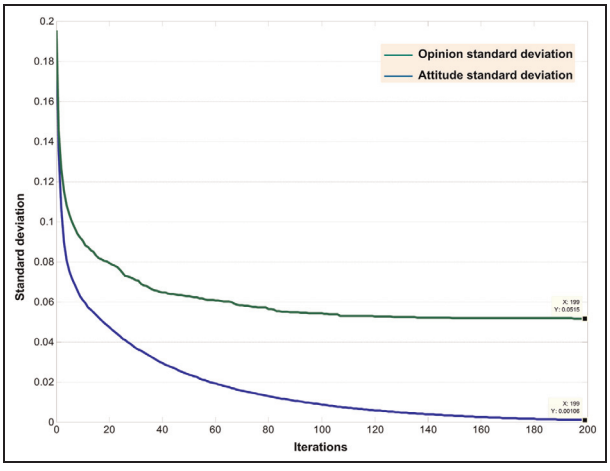

Figure 4. Comparison of opinion and attitude standard deviations.

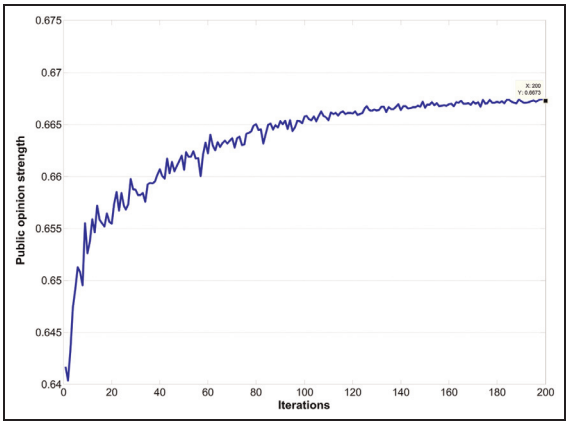

Figure 7. Average public opinion strength.

stable—in other words, the degree of pluralistic ignorance remained unchanged. In real-life terms, if the majority of individuals in a group share an attitude that is not in line with general public opinion, a small number of individuals whose opinions are in agreement with the general public's attitude may alter the original group opinion. The use of self-perception agents helps explain why even a single pioneer can influence change in group opinion; other models fail to identify this phenomenon. The combination of self-perception agents and social norms provides a sufficient explanation, since self-perception agents are free to exchange opinions at any time without considering social norms or

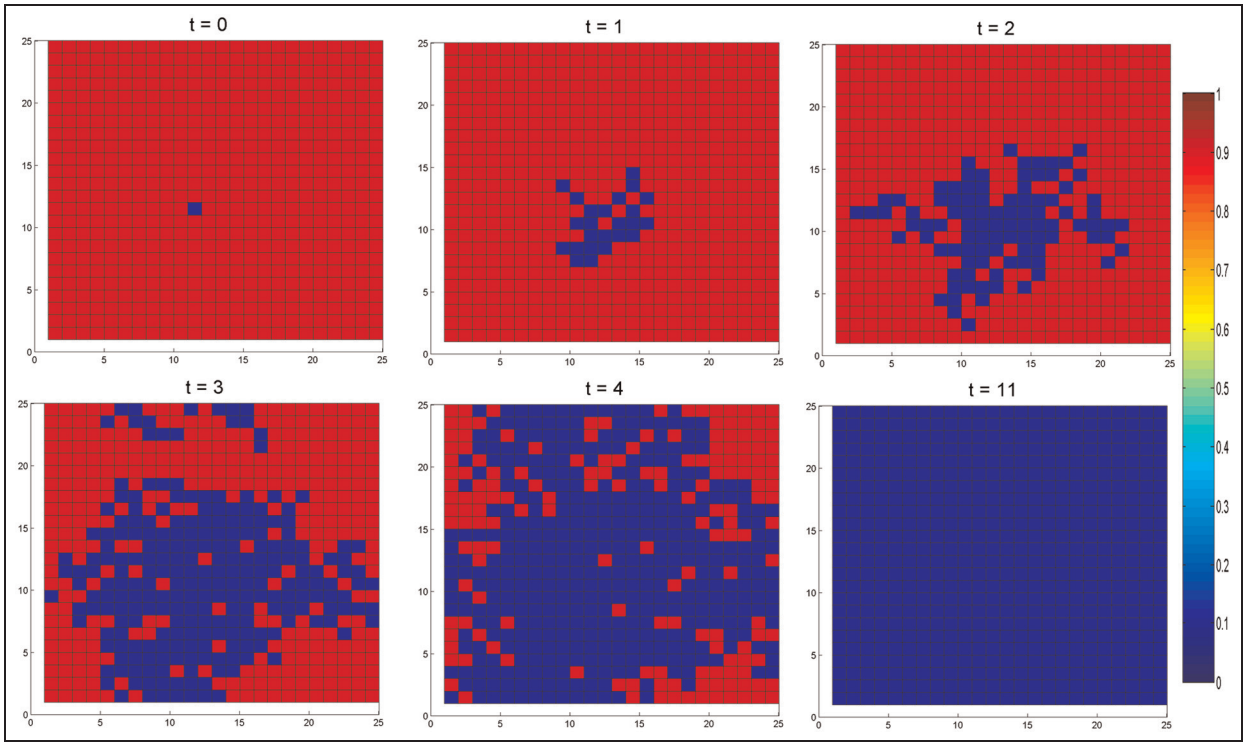

Figure 8. The breaking of pluralistic ignorance.

self-attitudes. In contrast, our self-perception agents take into account differences in their own attitudes and opinions under the influences of various public opinions.

Our agent model fits well with the rational action theory assertion that attitudes and social norms determine behavior. It is our hope that researchers in various disciplines will find our model useful for exploring complex issues (e.g., politics, religion, mass media) where small numbers of individuals have the power to change minds in the majority. To our knowledge, ours is the first attempt to create a new agent model based on social psychology theory, and to use experimental data to modify an existing agent model in a manner that supports the research efforts of social and computer scientists.

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