

# An Agent-Based Model of Indirect Minority Influence on Social Change

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## Abstract

The present study investigates how local majority and minority influences, in combination with an internal consistency process, affect cultural group formation and social change at a global level. We constructed an attitude updating algorithm based primarily on context/categorization–leniency contract theory. This theory postulates when, why, and how people are influenced by an ingroup majority to change an attitude (direct majority influence), by ingroup minorities to immediately change a related attitude (indirect minority influence), and eventually to change attitudes via an internal consistency process. These rules of social influence have been empirically validated in the field of social psychology. However, it is unknown how social influence processes following these rules at a local level lead to larger attitude group formation and social change (a process whereby a nascent opinion becomes the prevailing opinion) at a global level. The present study aims to fill this gap. With minimal assumptions, we implemented our social influence algorithm in an agent-based model to explore how majority and minority influences – along with internal consistency processes – each contribute to cultural group formation and social change. Our results reveal that persistently diverse attitude groups can emerge when minority and majority influences operate together; i.e., internal consistency is not a necessary condition, however it does facilitate attitudinal diversity and maintains it longer. Furthermore, even in the face of the direct majority influence, social change can occur via the indirect minority influence process when combined with internal consistency. We start here with a minimal model, but discuss directions for future expansions.

## Theoretical and Empirical Foundations

Social change is the process whereby a society adopts a new belief<sup>1</sup> which eventually becomes accepted as a norm. Diverse subpopulations are often seen as challengers to social stability and frequent catalysts of social change (Moscovici, 1976). Social psychologists have well-documented why, how, and when people can be influenced by such subpopulations. Furthermore, there are various theories on how the minority influence process can lead to social change (Mucchi-Faina, Pacilli & Pagliaro 2010); but little concrete research has been done to validate these postulates. A primary difficulty lies in the micro/macro differences in the phenomena: social change

<sup>1</sup> In this paper we use the terms 'belief', 'attitude', 'idea', 'opinion', etc. interchangeably to refer to individuals' epistemic relationship to an issue or topic.

happens at the level of society, whereas the minority influence process happens at the interpersonal and intra-individual levels. The present study aims to clearly establish the link between the minority influence process at a local level and social change at a global level by using an agent-based model. The agent-based model fosters examining cross-level links between agents' local behavioral rules and their generated global patterns. The model is primarily based on context/categorization–leniency contract (CCLC) theory (Crano 2010), a theory of majority and minority influences in the field of social psychology.

## Minority Influence

Identifying the underlying processes fostering the prevalence of diverse subpopulations and nascent ideas has been among the dominant puzzles of the social sciences. A substantial collection of studies about conformity and majority influences (Sherif 1936; Newcomb 1943; Asch 1951, 1952, 1955; Crutchfield 1955) could not adequately address the issue until Moscovici (1976, 1980, 1985; Moscovici & Faucheux 1972) took the first step to studying the power of minority influence. Since then, research on minority influence has explicated conditions under which a nascent attitude can permeate a population to displace a prevailing attitude on the same issue. The conditions include the nascent-idea-holding subpopulation's social identity (ingroup vs. outgroup), the attitudes' composition (consistent vs. inconsistent), the issue objectivity (objective vs. subjective), immediacy (immediate vs. delayed) and the focus of issue being influenced (directly to focal attitude vs. indirect influence) (Crano & Seyranian 2009). In this section, we review Moscovici's conversion theory, and illustrate how Crano's CCLC theory is developed to tighten certain aspects of conversion theory. In the following section we integrate the two theories to construct an algorithm of minority influence.

**Moscovici's conversion theory.** Moscovici's conversion theory contrasts the differences underpinning the motivational and cognitive processes between majority and minority influence. When individuals are confronted with an attitude counter to their own (whether the prevailing attitude or a nascent one) it creates inner conflict and tension, which results in a motivation to reduce this tension. The psychological discomfort is resolved via different processes depending on whether the counter-attitudinal source is the majority or minority attitude in their ingroup: minority

influence occurs through a validation process whereas majority influence occurs through a comparison process. Because the social majority may control resources or other sources of power, adopting the prevailing focal attitude is rewarding. Therefore individuals may change attitudes to comply with the group's consensus by simply comparing their own attitude to the prevailing one for some focal issue. This compliance reflects motives of group belongingness, but not an evaluation of the social majority's arguments for their positions. Consequently, the comparison results in an immediate direct influence, but the attitude change is typically superficial and may easily be changed again.

On the other hand, when someone in the society breaks the attitudinal unanimity, the person's ingroup members take notice of this salient event and the nascent idea captures the other ingroup members' attention. Even though nascent belief holders' positions are not conceived of as correct, their arguments are considered closely by the other ingroup members. At this stage of the validation process, the other ingroup members scrutinize the ideas in-depth. As a consequence, belief validation results in indirect influence (i.e., attitude changes happen in other, non-focal dimensions related to the nascent idea) and/or delayed focal attitude changes. Because ingroup members carefully evaluate the uncommon ideas, attitude changes induced by minorities via this path are stronger and last longer than those by unreflective conformity to the prevailing attitude.

According to conversion theory the most important condition for attitudes held by a minority of group members to influence other ingroup members is attitudinal *consistency*. Moscovici verified consistency's importance in his blue-green study (Moscovici 1969; 1980). Specifically, minority opinions are only influential when their attitudes are perceived as consistent and coherent (Clark 1990; Moscovici, Lage & Naffrechoux 1969; Wood, Lundgren, Ouellette, Busceme & Blackstone 1994).

**Crano's context/categorization–leniency contract theory.** Later research elaborated on the conditions under which attitudes held by a minority of ingroup members can have an influence on the rest of the group. This influence starts with changes to individuals' attitudes within the local ingroup, and eventually can percolate through the society and lead to global-level social changes in which the nascent idea replaces the prevailing one (Crano 2010; Martin & Hewstone 2001; 2010).

Crano's CCLC theory postulates that when ingroup members offer novel ideas that are not threatening to the ingroup they may be influential. His theory states that due to the leniency contract<sup>2</sup> between majority and minority opinions within a group, minority influences lead to both *immediate indirect attitude changes* (i.e., changes to attitudes besides the focal countervailing attitude) and also *delayed focal attitude changes* via an internal consistency process. By contrast, majority influences lead to immediate changes to

<sup>2</sup> The leniency contract refers to an implicit agreement between majority and minority within a group in which majority listens to the minority's dissent voice to maintain the viability and cohesion of the group, and the minority also agrees that a focal change is unlikely

the focal attitude, but do not affect supporting non-focal attitudes.

Thus, even though a direct change in the focal attitude is unlikely, there exists pressure to change indirect/related attitudes within the same cognitive constellation. Minority influence then becomes a function of message quality. A weak message may not lead to delayed focal change but rather temporary indirect change may occur in the direction of the gist of message. A strong message leads to an immediate indirect change, but an immediate focal change is unlikely. This minority influence toward indirect attitude changes has been empirically supported (Alvaro & Crano 1997; Crano 2000; Crano & Alvaro 1998; Crano & Chen 1998, Martin & Martin 2006).

Finally, indirect attitude changes may eventually lead to a focal attitude change via internal consistency processes. Because attitudes do not exist in isolation but rather are structurally interrelated in belief constellations, attitudes that occupy the same cognitive constellation may all be affected when one element of the set is changed. As indirect changes accumulate, delayed focal change can occur due to the motivation to maintain internal consistency within the cognitive constellation. (Crano & Chen 1998, p.1440; Fink & Kaplowitz 1993; Judd, Drake, Downing & Krosnick 1991; McGuire 1990; McGuire & McGuire 1991).

## The Agent-Based Model

First we present a modeling framework that matches the social psychology theories. We developed an updating algorithm for agents that captures the majority and minority influence processes as well as internal consistency (Figure 1). In the model, we assume  $N$  agents indexed by  $j$ . Each agent can be represented by a vector of  $M$  attitudes that take one of  $A$  values;  $a^j = [a^j_i] = a^j_1, a^j_2, \dots, a^j_M$ , where each  $a^j_i \in \{0, 1, \dots, A\}$ . We adopt the convention that agent  $j$  is the one being influenced and an agent  $k$  is the source agent who influences agent  $j$ . The source agent has *attitudinal consistency* if the source's attitudes take the same values (i.e.,  $a^k_i = a^{k_{i+1}} = \dots = a^k_M$ ).

First each agent identifies its *local ingroup*; the collection of agents with the potential to influence it. Then each agent randomly selects one member of its local ingroup to be an influence *source*. Each agent then compares a randomly selected *focal attitude* with that of its source agent. If the corresponding attitude of the source matches that of the agent (i.e.,  $a^j_i = a^k_i$ ), social influence is not initiated because the source affirms the agent's view (Steele, 1988; Sherman & Cohen, 2006). However, if the corresponding attitudes between the agent and the source differ (i.e.,  $a^j_i \neq a^k_i$ ), this discrepancy draws the agent's attention and evokes inner conflict (Festinger 1954; 1957). This motivates the agent to react. The reaction's form is contingent upon the majority/minority status of the source's attitude in the agent's local ingroup (Crano & Seyranian 2009).

If the focal attitude of the source is the majority attitude in the agent's local ingroup, then the agent conforms to the source (i.e., changes that attitude to match the source). On the

other hand, if the focal attitude is the minority attitude in the agent's local ingroup, then the agent examines consistency among the focal and related attitudes that the source has. At this time, the agent does not and/or cannot examine all the attitudes that the source has in its belief vector due to cognitive limitations.

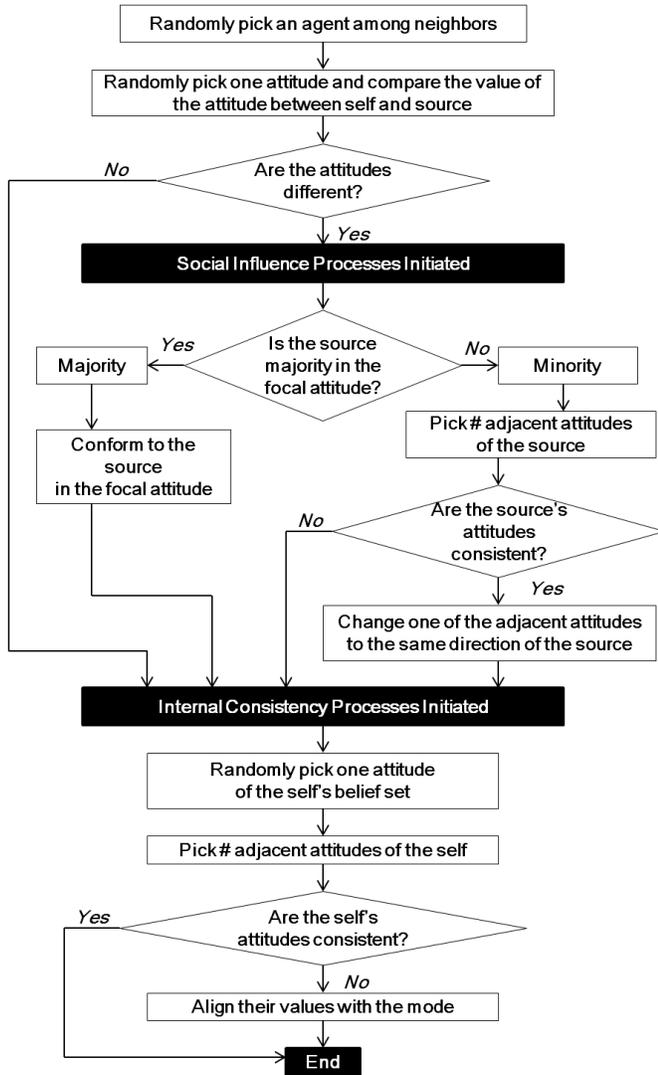


Figure 1. An Algorithm of Majority and Minority Influence and Internal Consistency Processes

As demonstrated by research on cognitive bias and bounded rationality (Simon 1957). For example, we are often *cognitive misers* (Fiske and Taylor, 1984, 1991) who prefer to process information efficiently by utilizing heuristics in our adaptive toolbox (Gigerenzer and Selten 2001, pp.37-50); people also act as *lay scientists* who systematically build knowledge from bits of evidence. Thus, in this model agents randomly select a few closely related attitudes from the source's belief vector and examine their consistency. If the closely related attitudes of the source are consistent (e.g.,  $a_{i-1}^k$

$= a_i^k = a_{i+1}^k$  for focal attitude  $a_i^k$ )<sup>3</sup>, the agent changes one mismatched attitude out of the related attitudes (e.g.,  $a_{i-1}^k$  or  $a_{i+1}^k$ ) to match the source's focal attitude. However, if the attitudes are not consistent, the agent does not change any of its own attitudes. In sum, majority influence through conformity is narrow and immediate produces changes to the focal attitude while minority influence (through conversion) is less common and indirect, but has a broad impact when it happens.

Upon completion of the social influence process, the internal consistency process is initiated: these two processes are independent in the current model. In this stage, all agents turn their attention to their own belief set in order to tune their attitudes to be consistent. Each agent  $j$  randomly picks one attitude (i.e.,  $a_i^j$ ) in their belief set and examines if the chosen attitude and its adjacent attitudes have the same value. If the examined attitudes are not consistent, the agent tunes the chosen attitude toward the adjacent attitudes. This can be achieved, for example, by setting it to the modal value among adjacent values (if one exists) or by setting it to match a random adjacent attribute.

### An Example

To demonstrate these processes we first consider a case in which each agent has five attitudes ( $M=5$ ) with binary attitude values (i.e.,  $a_i^j \in \{0,1\}$ ). Agent  $j$  (marked in bold with gray shading in Figure 2) has an attitude vector of  $a^j = \{11001\}$ . Following our algorithm above, the agent considers its eight Moore neighbors (solid border) as its ingroup and makes a uniformly random selection of one to be its source for this turn. Assume the top left agent of the ingroup is chosen as  $k$  so  $a^k = \{01111\}$ . Next the agent randomly picks one attitude out of the five. Let's say  $a_3$ , the 3rd attitude, is chosen. Agent  $j$  compares its value ( $a_3^j=0$ ) with the corresponding attitude of the source agent  $k$  ( $a_3^k=1$ ). Because  $a_3^j \neq a_3^k$ , agent  $j$  next evaluates the majority/minority status of the source agent  $k$  in the local ingroup in terms of the 3<sup>rd</sup> attitude. Within  $a^j$ 's ingroup, there are six agents with  $a_3=0$  and three agents with  $a_3=1$ ; therefore the source's attribute value of 1 is in the local minority. Note that this evaluation is independent of the global prevalence of values for  $a_3$ .

01001	10001	10101	01011	10101	00101	11001
00100	01001	11011	10000	11111	11001	01111
01110	01100	01111	10010	11011	10000	00010
01010	01110	11010	<b>11001</b>	01001	01101	10110
11011	10010	00001	10100	00110	10001	10111
10110	10101	01011	00101	10111	01111	00000
01011	01111	11101	00011	00110	11010	00100

Figure 2. An example demonstrating the agent updating process.

Now agent  $j$  evaluates whether the source  $k$  is consistent in its attitudes within a cognitive constellation of  $a_3^k$ . The adjacent attitudes  $a_2^k$  and  $a_4^k$  are considered, so the source's attitudes are consistent if and only if  $a_2^k$ ,  $a_3^k$ , and  $a_4^k$  are all

<sup>3</sup> The attitude vector is assumed to wrap around so that  $a_1^k$  and  $a_M^k$  are adjacent.

same. In this example, the values of  $a_2^k$ ,  $a_3^k$ , and  $a_4^k$  are all 1, therefore the agent  $j$  changes one of its mismatched non-focal attitudes to match the source's value. Among the two constellation attitudes  $a_4^j$  is the only mismatched one, thus agent  $j$  changes the value of  $a_4^j$  to the source's value and so becomes  $d = \{11011\}$ .

However, if the agent from the bottom right of the ingroup (with attitude vector  $\{00110\}$ ) is chosen as the source instead, due to its attitudinal inconsistency (i.e.,  $a_2^k = 0$ ,  $a_3^k = a_4^k = 1$ ), agent  $j$  will not change its attitude at all. Or if the agent to the left of agent  $j$  is chosen as the source, agent  $j$  will not change its attitude because the source affirms agent  $j$ 's attitude.

Going back to the first case, upon completion of the social influence process in which agent  $j$  has updated its belief vector to  $d^j = \{11011\}$ , the agent  $j$  next randomly picks one attitude out of five again...let's say  $a_2$ . Agent  $j$  examines if the chosen attitude  $a_2^j$  and its adjacent attitudes  $a_1^j$  and  $a_3^j$  have the same value (*internal consistency*). Because the examined attitudes are not consistent (i.e.,  $a_1^j = a_2^j = 1$ ,  $a_3^j = 0$ ), the agent tunes them to be the same value of the mode (in this case 1). As a result agent  $j$ 's attitude vector becomes  $d^j = \{11111\}$ . Each agent undergoes the same process (either synchronously or asynchronously) for each iteration of the model.

### Implementation in Netlogo with Minimal Conditions

We implemented this attitude updating algorithm in a cellular automata-style agent based model using Netlogo 5.0.5. To keep the dynamics clear we utilize the minimal conditions necessary to capture the effects of majority and minority influence and internal consistency. In our basic setup 1600 agents populate a 40-by-40 toroidal square-grid topology (no empty spaces). Ingroups are defined as the eight agents in the Moore neighborhood – just as above.<sup>4</sup>

Each agent has two attitudes and each attitude takes binary values: one attitude is represented as color ( $a_1^j$ : 0 = yellow, 1 = blue) and the other as shape ( $a_2^j$ : 0=circle, 1= square).<sup>5</sup> Thus, there are four different agent states: yellow circle (i.e.,  $d^j = \{0, 0\}$ ), yellow square (i.e.,  $d^j = \{0, 1\}$ ), blue circle (i.e.,  $d^j = \{1, 0\}$ ), and blue square (i.e.,  $d^j = \{1, 1\}$ ). Consistent agent states are therefore the yellow circle and blue square. When checking consistency the agents simply change the focal attitude to match the other attitude.

We define a *cultural group* as a collection of contiguous (including corner connections) agents sharing the same value for all (both) attitudes. We are interested in the number of culture groups as a measure of the social diversity of a given set of attitudes. However, not all groups should necessarily be weighted equally: the smaller a cultural group is, the less it contributes to the society's diversity. We account for this by reporting both the number of groups and the effective number

<sup>4</sup> The ingroup for the majority/minority influence algorithm can be defined by a variety of neighborhood topologies (e.g. grids of different types or irregular networks), the geographies of moving agents, dynamic social connections, abstract associations, etc.

<sup>5</sup> Squares are shaded slightly darker to be more easily discernable.

of groups. The effective number of groups is calculated using the inverse Simpson index (Page 2010).<sup>6</sup>

## Simulations and Results

We simulated the agent based model to answer two questions of interests: (1) Under which rules can an attitudinally diverse population persist? (2) Under which rules can social change occur (i.e., a nascent idea becomes prevalent)? For each combination of rules and initial conditions (described below) we performed 100 runs of the model until (a) all the agents have the same attitude, (b) no agents can change attitudes, or (c) 10,000 time steps (to terminate non-equilibrium runs and facilitate analysis of extremely long convergence times).

At each step we calculate the percent of the population of each color and each shape – since there are only two values for each attribute, percent yellow is one minus percent blue and it suffices to present percent blue and percent square. We also determine the number of groups of each attitude, combined attitude cultural groups, and the effective number of groups.

### When do diverse cultures persist?

To identify conditions under which a diverse cultural population persists we initially create a population with equal numbers of both colors and both shapes. The two attitudinal dimensions are assigned independently and the spatial distribution of attitudes is uniformly random.

**Majority influence.** The dynamics of local strict majority influence processes are already well-known to science. These systems converge quickly (~50-100 iterations) into amorphous global patterns of each cultural group. The attitude distribution becomes skewed in a way that is dependent on initial conditions and stochastic elements, but with no systematic bias toward any attitude. When internal consistency processes are in play, majority influence performs much the same as if there were just one attitude with two values.

**Minority influence.** This process acts to balance the prevalence of each attitude, so with equal initial quantities and a random initial arrangement, minority influence alone is a continuous and balanced stochastic mixing of the attributes across the agents. Although there are typically hundreds of cultural groups, none of them are persistent. In order to maintain internal consistency the attitudes have to line up in alternating rows or columns thus creating 40 groups of equal size in equilibrium.<sup>7</sup> However, it often takes many thousands of iterations to reach this equilibrium and in the process there are usually many fewer groups in play.

<sup>6</sup> The inverse Simpson index is a measure of the effective number of types in a population. It is calculated as the inverse of the sum of the squared proportional sizes of the groups:  $(\sum_i g_i^2)^{-1}$ .

<sup>7</sup> Obviously this value depends only on the dimensions of the space – we find 40 groups because we use a 40x40 world and the attitudes alternate. Using an odd number of spaces (e.g. 39x39) forces a vertical or horizontal strip of constant, stochastically balanced fluctuation.

### Majority and minority influence without consistency.

These processes together form large, consistent cultural groups with mixed-attitude boundaries that converge slowly (over thousands of iterations) to a single consistent attitude culture (Figure 3). The groups are consistent despite internal consistency being off because in minority influence, imitation only occurs when the targets' attitudes are consistent.

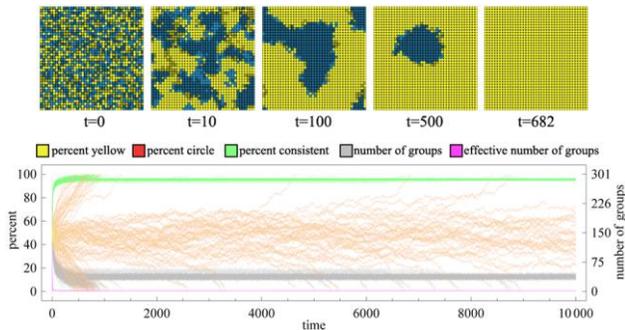


Figure 3: Results of simulation with majority and minority influence only. Screenshots from one run illustrate the spatiotemporal dynamics of consistent group formation and mixed boundaries. Plots for 100 runs showing that both outcomes are common. Most runs reach global conformity in <1000 iterations, but several take more than the 10,000 simulated. Lines appear orange because they are yellow layered on red when consistency is high.

### Majority and minority influence with internal consistency.

Majority and minority influences, in combination with internal consistency, create a system which has more, smaller cultural groups that come in and out of existence at a high rate. Even though the system eventually converges, it typically takes much longer (ten times the iterations). Also, the majority and minority status of attitudes is erratic at the global scale: social change often happens, but it often switches back throughout the runs (Figure 4).

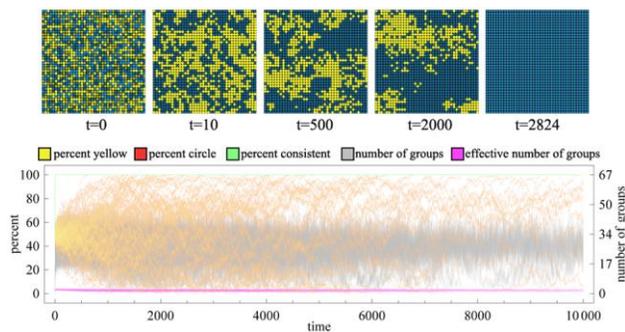


Figure 4. Results with majority and minority influence and internal consistency. Screenshots reveal the more fragmented nature of the groups and the lack of long-lasting coherent groups. Erratic time series and highly variable halting times across 100 runs reflect the stochastically balanced mechanisms.

**Summary.** Populations of diverse cultures will persist under either minority or majority influence alone (with or without internal consistency). When minority and majority influences work together, the system will always converge to a uniform population; however, this may take an extremely long time and even longer when internal consistency is in play. Interim

patterns of heterogeneity are more dynamic when internal consistency is in play.

### Which mechanisms generate social change?

Next, we simulated the model to validate Crano's conjecture that minority influence at the local level can lead to social change at the global level via an internal consistency process. We also explore whether social change can be led solely by minority influence, and whether it is robust against the effects of majority influence. We initialize the system with a randomly chosen 1% of the agents holding the nascent attitude (yellow; i.e.,  $a_I^j = 0$ ) while maintaining equal initial populations of shape.

**Minority influence alone.** The indirect minority influence process will always spread a nascent attitude from 1% of the population toward 50% of a population. After reaching approximately half of the population, however, minority influence balances the two attitudes in a constant stochastic churning of both color and shape (as described above). Thus indirect minority influence alone cannot lead to social change. (Figure 5). Minority influence plus internal consistency also brings the population up to the roughly 50% point in every run, after which the dynamics mirror the case above.

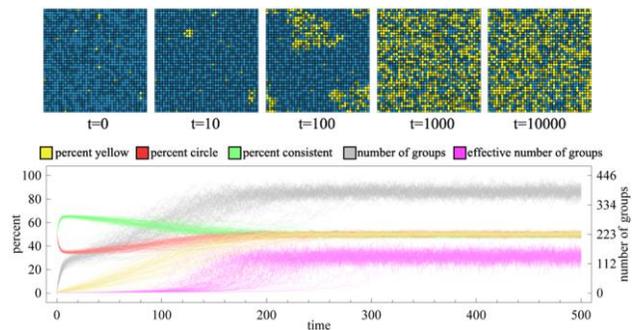


Figure 5. Screenshots show the growth in popularity of the nascent attitude up until the system becomes stochastically mixed at roughly equal proportions. Note also the alignment of the shape attitude in the early stages into locally balanced configurations. Though every run is distinct in its particular spatiotemporal arrangements, the dynamics are consistent across 100 runs. This plot is truncated to 500 iterations to highlight details of earlier periods.

**Minority influence facing majority influence.** In the face of majority influence, however, minority influence cannot spread the nascent attitude. Majority influence dominates minority influence process on the color attitude and so the system quickly converges to all blue. Thus social change does not occur. Minority influence (which imitates an attitude only when consistent) quickly eliminates circles from the population as well as to establish a monoculture (Figure 6).

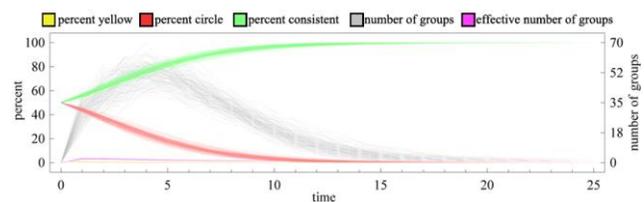


Figure 6. With only 1% of the population initially holding the nascent attitude, majority influence quickly dominates the effects of minority influence and uniformly spreads the prevailing idea.

**Minority influence and internal consistency facing majority influence.** Consistent with Crano’s conjecture, the indirect minority influence process in combination with internal consistency *can* spread an initial minority position in the face of majority influence. Even though a system converges to the prevailing attitude in 75% of the runs (Figure8), there are chances for a nascent attitude to temporarily or even permanently be globally adopted (i.e., social change occurs) (Figure7).

Note that the initial 1% of agents that are yellow is immediately expanded in the first iteration when agents enact the self-consistency rule. Approximately half of the blue circle agents will make themselves consistent by becoming yellow circles – that’s an additional 24.25% of the agents on average. We address this in future work (described below) by identifying the relationship between the number of initially consistent yellow agents and the success of social change.

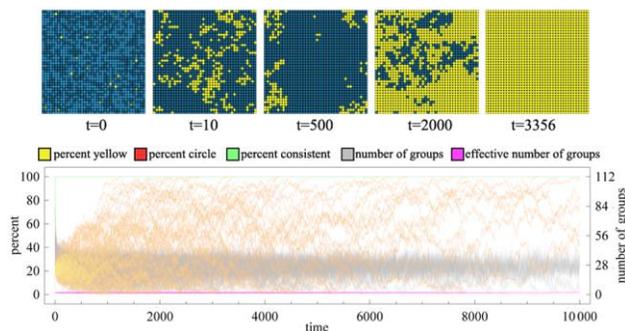


Figure 7. Screenshots from one run demonstrate the high volatility of the attitude proportions. The time series from 100 runs highlight this long-lasting volatile behavior.

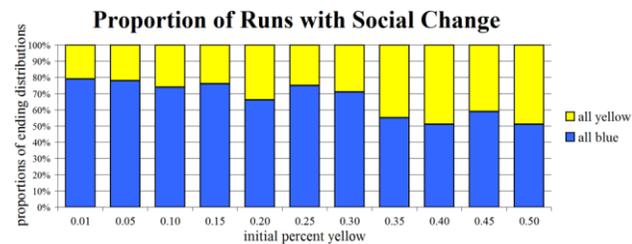


Figure 8. This chart shows the proportion of 100 runs for each ending distribution of the color attitude with all three rules activated. These runs were all taken to equilibrium regardless of the time step. Despite the high volatility of the dynamics, there is an increasing tendency to achieve social change with increasing initial percent holding the nascent idea.

**Summary.** In the face of the direct majority influence, social change can occur via the indirect minority influence process in combination with the internal consistency process. The indirect minority influence process alone (without the internal consistency rule) cannot spread an initial minority position

against the direct majority influence. However, this may be the result of an artifact of increasing the initial population of yellow agents through the internal consistency rule.

## Discussion

The present study aims to investigate how direct majority and indirect minority influences at the local level, in combination with an internal consistency process, lead to cultural group formation and social change at a global level. The algorithm was constructed based primarily on the psychological rules posited in Crano’s CCLC theory.

Majority influence immediately influences an individual to adopt the focal issue attitude due that is most common among its peers. The rules of minority influence are more complex. Ideas held by a minority of one’s ingroup can also be influential, but they act indirectly on a non-focal attitude in the same attitude constellation. Furthermore, this influence only occurs when those holding the minority view are consistent in their own views. As indirect attitude changes accumulate, delayed focal change can occur through a motivation to maintain internal consistency. Indirect changes followed by consistency changes can lead an idea originally held by just a few individuals to take hold in a whole population in the right conditions. This is social change.

We tested for social change by seeding a population of 1600 agents randomly with 1% having the yellow attribute, while the shape attribute remains equally distributed. Majority influence alone, or with internal consistency, quickly removes the nascent idea from the population. Minority influence – alone or with internal consistency – reliably brings the nascent idea from 1% to 50% of the population, but naturally cannot achieve social change because the mechanism always promotes the attitude that is less popular.

When majority and minority influence are used together, but without internal consistency, majority influence dominates and the population quickly converges to the prevailing idea. When internal consistency is added, half of the initial blue-circle agents immediately become yellow-circle agents. This boost to the nascent idea holders often suffices to stop quick majority domination. Furthermore, the requirement that agents be consistent ensures that minority influence is engaged in each individual’s mechanism because the minority attitude is always consistent. Although social change is possible under these conditions, it is unlikely. The likelihood depends on the initial percent of the population holding the nascent idea, and also on the micro-structure of their locations and the many stochastic elements in the model. Finally, although these simulations always end in one homogeneous equilibrium or the other, the time to reach the equilibrium can be extremely long (e.g., as much as 20,000 iterations). With mixed ideas persisting for so long, other mechanisms may interject to alter the balance.

In addition to social change, we are interested in the ability of these psychological mechanisms to maintain a diverse set of attitudes within a population. Cultural groups are communities of connected individuals who share all their (relevant) attitudes. The formation of coherent cultural groups from a random initial distribution of attributes is

important because these cultural groups can provide safe proving grounds for incubating new ideas.

Majority influence alone, or with internal consistency, succeeds in producing large cultural groups. These grouped patterns are equilibria because each agent's local neighborhood of eight agents has at least four agents of the same attitude. Without consistency checks the attributes are influenced independently, creating a multi-layered pattern in which all combinations of the attitudes persist.

In contrast to the equilibrium cultural groups formed by majority influence, the groups formed by minority influence are in constant flux. Without internal consistency, the process acts as a balancing stochastic process that ensures all attributes are roughly equally represented. There are a large number of cultural groups, but they are very small and are not persistent. They fail to capture the phenomena we wish to pick up as cultural groups; instead, they are just temporary patches of attributes. Adding consistency induces another equilibrium condition, but a mixed one. Every agent must be the minority of its local neighborhood and this is only achievable by having an even number of straight rows or columns. This is also not the sort of cultural groups identified in the literature, but rather an artifact of the model.

Combining all three mechanisms produces an interesting dynamic of cultural groups reminiscent of coherent structures in Conway's Game of Life (Conway 1970), although the stochastic elements in the current model complicates a microscopic analysis of recurrent patterns. Large and small groups of both consistent cultures can persist for long periods, "float" across the screen, rise up, and die out. As is the case with any cellular automata, these seeming movements are the result of changing attributes of stationary agents, but the population-level patterns are intriguing dynamical features of these mechanisms not anticipated by the social psychological theories.

Other features of these simulations worthy of discussion include the long time-spans of many runs, the non-equilibrium nature of some behaviors, and the volatility of population-level patterns. The preferred analytical technique among many social scientists involves equation-based modeling that focuses on equilibrium of outcomes or distributions. However, our results highlight the need to model and understand the dynamics of the long time-spans before equilibrium conditions are reached. Furthermore, in some cases we can foretell the outcome after a few iterations through feedback effects among clusters. In other cases (such as when all three mechanisms are active), the population can shift widely from one extreme to the other in just a dozen iterations, making reliable prediction impossible. Although we report the distribution of equilibria as a function of initial population attributes, a deeper analysis of the interim dynamics is more likely to improve our understanding of the phenomena.

### Limitations and Future Direction

Our goal in this paper is to present a minimal model capable of embodying the mechanisms of majority and minority influence as described in the social psychological literature. These theories, however, are purported to have much wider and deeper application. In order to fully engage the literature

expansions must be made to both the simulations and the theories.

**Expanded attitude space.** The first obvious augmentation is to incorporate longer attitude vectors and more variations per attitude. We would like to test the sensitivity of the dynamics to the size of this attribute space as in Axelrod (1997), but the theories themselves need further refinement to handle influence in cases in which no attribute holds a majority or clear minority. What influences reign in a pluralistic environment?

**More sophisticated agents.** Our agents fully populate a torus space in a regular lattice – a common feature of theoretical agent-based models. More realistically agents would migrate, change interaction partners, have heterogeneous neighborhoods, and these behaviors would also be contingent on local opinions. Furthermore they could reproduce, mutate, or undergo selection processes. With this prototype model, we are able to clearly ascertain the link between agents' behavioral rules and system-level patterns.

**Internal consistency force.** Our findings show that the internal consistency process plays a key role in social change. The next question is how the strength of internal consistency affects social change; specifically, what is the relationship between the strength of internal consistency checks and the occurrence of social change? This question can be answered by varying the probability that a check is performed, and/or by changing the number of attitudes that are put in line (after we add more attributes).

**Objective vs. subjective issues.** Attitudes may address objective or subjective issues. *Objective issues* have a correct belief, such as the weight of a particular ox. *Subjective issues* (aka, mere opinions such as what color is "in" this season) reflect the converging of ideas in the population. Crano argues that for objective issues, a nascent attitude is scrutinized by counter-attitudinal individuals, which may lead to an immediate focal change if the attitude is correct. Depending on objectivity/subjectivity of issues, different rules may govern agents' influence processes. In future studies, we can construct and compare two models where different rules are implemented depending on objectivity/subjectivity of issues.

## Conclusions

Majority and minority influence are important and well-studied topics in the field of social psychology. Due to the limitations of empirical methodologies, however, theories and empirical research focus mainly on explicating interpersonal and intra-individual psychological rules of social influence. They neglect how such rules lead to larger level group phenomena such as social change and cultural group formation. Most of the claims linking interpersonal/intra-individual-level rules and group/society-level patterns are merely conjectures. The present study is an attempt to provide a detailed connection between the individual and social layers through simulation.

We implement the social influence rules postulated in Crano's CCLC theory in an agent-based model with minimal assumptions. Simulation results demonstrate that in the

current formulation the indirect minority influence alone cannot lead to social change in the face of the direct majority influence. However, our results also show that in combination with an internal consistency rule, the three processes together can in some scenarios lead to social change. Furthermore, both the majority and minority influence processes can lead to the formation of diverse cultural groups of distinct kinds.

The current study shows the partial validity of the conjecture that the social change at a societal level occurs through indirect minority influences process at the local level in combination with the internal consistency process. Our study reveals that all three forces are necessary for social change. The indirect influence process triggered by counter-attitudinal ingroup minority alone cannot make social change occur in the face of majority domination. What is necessary is individuals' motivation to maintain internal consistency in their attitudes, to emulate consistent minority attitudes, and to adopt popular ideas both old and new.

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