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RESEARCH ARTICLE

A dynamic model of segregation and integration: Incorporating adaptive intolerance, media bias, and conformity into the Schelling framework

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Abstract

Thomas Schelling introduced his agent-based model of segregation in 1971 and concluded that even when there is a low amount of intolerance within society that segregation will develop if people follow their individual preferences. A large body of literature building of this framework has been built and has bolstered this claim. This paper aims to take the same framework but instead look for ways to get to an integrated state. We focus on Allport's contact hypothesis that states that if there is equal status among groups, common goals among groups, and an institutional mechanism supporting intergroup contact then intergroup contact can reduce prejudice. We incorporate the contact hypothesis by having individuals adjust their intolerance based on their current neighborhood composition and the ease of conforming to their surroundings. Furthermore, we add in positive and negative media effects, as individuals are likely to get information about an outgroup from the media (e.g., news, TV, movies, etc.) that they consume. We find that having a society composed of individuals who do not easily conform to their surroundings and displaying positive examples of both groups in media promote integration within society.

Author summary

Thomas Schelling's model of segregation was an important advance in modeling segregation. His framework demonstrated that segregation can develop even with a relatively low level of intolerance among agents. Many researchers have built upon this seminal model, yet few subsequent models have incorporated an adaptive tolerance. Our model addresses this by incorporating the effect that the media has on changing intolerance. It also applies the tenets of the contact hypothesis, which states that under certain conditions, contact has the ability to reduce prejudice. We use a flexible mathematical function—similar to what is observed

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in data—as a reaction function, centering on a conformity value. This conformity value determines whether agents are willing to adapt their tolerance based on their current neighborhood composition. We find that when this conformity value is relatively small, an integrated state arises. Furthermore, this conformity value influences how effectively media that portrays the outgroup in a positive light can steer the agents toward an integrated equilibrium.

Introduction

Thomas Schelling created an agent-based model (ABM) of neighborhood segregation in 1971 [1]. The model showed how individual preferences can lead to larger scale segregation within a population. Schelling's research revealed that segregation can occur even when individuals can tolerate being in the minority if agents move according to their individual preferences.

Many extensions to Schelling's segregation model have been implemented, adding components such as housing markets [2,3], networks [4], reinforcement learning [5] and external meeting places [6]. Many extensions of Schelling's work land on the idea that segregation is quite stable, with only a handful of papers exploring factors that lead to integration [7].

Segregation has been proven to have negative effects on society [8]. For instance, it limits economic opportunities for Black individuals [9] and is associated with a reduction of access to healthy food options for Black individuals [10,11]. Therefore, avoiding segregation should be a priority, and seeking potential solutions would benefit the public.

In this paper, we build off Schelling's segregation model in order to find situations where integration occurs. The main extensions included in this model are the effects of intergroup contact and media influence. Intergroup contact in this model is based on Allport's contact hypothesis [12]. Allport postulated a hypothesis that intergroup contact reduces prejudice when there is equal status among groups, common goals among groups, and an institutional mechanism supporting intergroup contact. In our model we will be considering contact by itself, assuming the other factors are already in place.

While this assumption may appear to be load-bearing to our analysis, Allport's contact hypothesis has been tested in numerous situations. Even when not all of Allport's optimal conditions are met, a reduction in prejudice is still frequently observed [13–16]. For example, a 2006 meta-analysis by Pettigrew and Tropp [13] found a consistent reduction in prejudice across various settings; this reduction was largest when all of Allport's conditions were met. Furthermore, a 2018 study by Hodson et al. [14] theorized that contact itself can induce a psychological change, fostering a more flexible and open worldview and promoting multiculturalism.

This paper is not the first paper to incorporate adaptive tolerance and the contact hypothesis into their analysis of segregation. Urselmans and Phelps [17] developed a model where agents became more tolerant if they were satisfied with the percentage of their ingroup and if that agent comes into contact at least one agent from their outgroup. Agents will decrease in tolerance if they are surrounded by agents from the outgroup. The amount the tolerance changes is fixed being equivalent for increases or decreases in tolerance and is set before the simulation begins.

The authors also included migration into their analysis, controlling the final proportion of migrants to native agents and the number of migrations waves (if the number of waves were greater than one then the amount of migrants each wave were adjusted to hit the desired migrant-to-native proportion).

Their work focused on migration and showed that under their framework that the tolerance will polarize to the extremes with agents becoming extremely tolerant or extremely intolerant. Here, the options for the equilibrium (ex: extremely tolerant, extremely intolerant or a mix of intolerant and tolerant) is determined by the amount that tolerance changes and proportion of native and migrant agents.

We believe our work adds to the body of work that analyzes segregation via agent-based modeling by varying the amount that agents adjust their tolerance based on that agent's neighborhood composition. We believe that this link between agents reaction and the neighborhood composition is plausible due to the survey results in the 1976 and 1992 Detroit Area Survey which find people's willingness to move to an area is dependent on the neighborhood current composition [18,19].

Frequently, individuals from different groups do not interact with one another directly. As a result, media has become a significant influence on people's perceptions of out-groups. Research has demonstrated that media can either increase or decrease an individual's prejudice levels, depending on how the out-group is portrayed [20,21]. To account for this, we have included mechanisms that can adjust an agent's tolerance level based on the type of media they consume. Finally, while social position (such as status) and social roles [22,23] have also been shown to strongly affect the stereotypes applied to a social group, this paper focuses specifically on the role of media.

Individuals move for various reasons outside of dissatisfaction with the racial or ethnic composition of their neighborhood. The Joint Center for Housing Studies (JCHS) [24] states "40 percent of movers did so for housing-related reasons in 2019, 27 percent moved for family-related reasons, 21 percent for job-related reasons, and 12 percent for other reasons". Hence, the model also incorporates movement that is due to factors outside of the composition of an agent's neighborhood composition.

We recognize that the Schelling framework emphasizes individual mechanisms that cause segregation rather than societal factors that contribute to it, such as zoning laws, infrastructure that separates racial groups, and local racial covenants [25,26]. Our current investigation is introductory and lays the foundation for future work that builds upon this analysis.

Materials and methods

We create agents on a 51×51 grid. During the initial phase of the simulation, each grid cell has a probability, determined by the **density** parameter, of having one agent placed on it. The agent that is generated also has a probability of being either red or green, which is controlled by the **red-percent** parameter. The color of the agent indicates its "racial" group. Note that we performed a similar experiment to the one presented in Fig 4 using a grid size of 101×101 and found comparable equilibrium heatmaps (see S1 File).

We take inspiration from the original Schelling model and assume agents have an intolerance level at timestep t, I_j^t, represented as the desired percentage of their neighbors who are from the same group. At the beginning of the simulation all agents are given the same intolerance is given by I^0. We define a neighborhood using the Moore neighborhood, which consists of the eight grid cells surrounding an agent. If the proportion of neighbors from the same group is lower than an agent's desired percentage, they will move to another location that meets their desired percentage. In our model, if no empty grid cells satisfy an agent's desired neighborhood composition, the agent will move to the empty space with the highest percentage of agents from the same group.

We have also incorporated a parameter, **non-racial-move**, which allows for a small chance of agents moving for reasons other than neighborhood composition, such as job changes, the housing market, or school systems. This addition reflects the reality that individuals do not exclusively base their moving decisions on neighborhood demographics. Alongside the probability of agents moving due to dissatisfaction with their neighborhood, there is an additional probability, at each time step, that agents will randomly move to an empty grid cell, disregarding neighborhood composition.

We borrow measures of segregation from Wilensky's NetLogo Segregation Model [27]. The level of segregation—assigned to variable **percent-similar**—is given by the total number of agents in each neighborhood that are similar to a given agent on a grid divided number of agents in each neighborhood. An equivalent way of computing **percent-similar** is to compute the average number of similar agents divide by the average number of neighbors. This means that if one starts with a population split evenly between the two groups, an integrated equilibrium should have an average percent similar value close to 50 percent.

The stopping condition is determined by tracking **percent-similar** and the mean intolerance $\overline{I^t} = \sum_j I_j^t / N$—$N$ is the number of agents. We keep only the last 100 timesteps. If the standard deviation of **percent-similar** is within 1 and the standard deviation mean intolerance is within 0.5 then the simulation stops. This stopping condition was validated through experiments detailed in the Supporting Information (see S1 File), which confirm that the simulation stops only after it has sufficiently equilibrated.

Below, we lay out how intergroup contact and media effects will be implemented in the simulation. Please note one can reference definitions of the parameters within the model in Table 1.

Intergroup contact

We look to develop a function that can capture a wide breadth of potential reactions to an agent's neighborhood. We first point to the Detroit Area Study and research conducted by Farley et al. [18,19]. The survey results are portrayed in Fig 1. Note that we reporting the aggregated data presented in [18] from the Detroit Area Survey and we accessed this data July 2022.

These studies suggest that Black individuals are open to living in integrated areas and may even prefer integration over a purely Black neighborhood. In contrast, White individuals tend to live in almost purely White neighborhoods and have less contact with Black individuals. As a result, integration may be less appealing to them. We conjecture that this may be due to the fact that Black individuals come into contact with White individuals more frequently compared to White people.

The survey data suggests that we need to have a function that can capture negative reactions to neighborhoods that are more diverse or less diverse than desired. The reaction function in Sabin-Miller and Abrams's work on political polarization [28] demonstrates the desired behavior. In their work, they develop an opinion model where individuals move towards political opinions that are close their own, but will be repulsed by opinions that are far away. We assume similar dynamics hold for intolerance values of the model's agents.

Table 1. Parameter definitions. Table of parameters used in the model with descriptions.

Parameter	Description
density	The expected proportion of the grid that will be occupied by an agent
red-percent	The percentage of the population from the red group
non-racial-move	The probability that an agent will move to a random empty square at each time step. Ignores neighborhood composition.
I_j^t	The minimum proportion from the same group in an agent's neighborhood that satisfies that agent
I^0	Initial minimum proportion from the same group in an agent's neighborhood that satisfies that agent
$\%_j^t$	The proportion from the same group in an agent's neighborhood
λ	The willingness for an agent to conform to its neighborhood
$g(j)$	Media consumed by agent j

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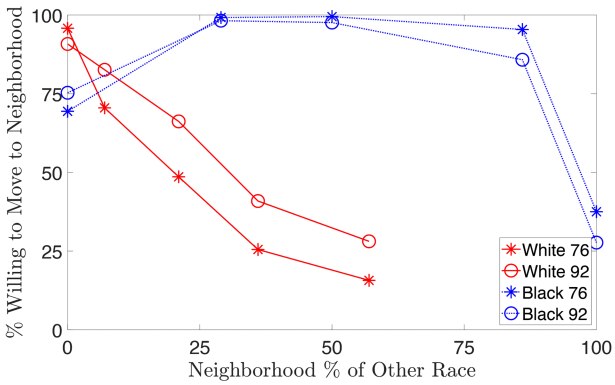

Fig 1. Results from the Detroit Area Survey. We plot the response data from the 1976 and 1992 Detroit Area Survey [18,19]. Participants in this survey were asked if they were willing to move to a prospective house given the percentage of the "other" race—Black for White individuals and White for Black individuals—in the neighborhood. We can see that the percentage of White respondents quickly drops as the percentage of the other race rises. The responses from Black individuals were U-shaped, where a neighborhood with a 50-50 split between White and Black people were the most preferred and all-Black neighborhoods or all-White neighborhoods were not as desired.

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In our model, agents compute the absolute difference of the intolerance I_j^t to the current percentage of individuals in its Moore neighborhood that are from the same group $\%_j^t$ (this includes the agent itself). Specifically, the agents check if the absolute difference, $|\%_j^t - I_j^t|$, is bigger or smaller the "conformity" parameter λ.

Conformity, represented by the parameter λ, determines the degree of tolerance an agent has for the difference between its own intolerance and the neighborhood composition it desires. If the absolute difference between the neighborhood percentage and its intolerance value is smaller than the conformity parameter, i.e., $|\%_j^t - I_j^t| < \lambda$ then the the intolerance value will: (1) increase if the neighborhood percentage is larger or (2) decrease if the neighborhood percentage is smaller. If the absolute difference between the neighborhood percentage and its intolerance value is larger than the conformity parameter, i.e., $|\%_j^t - I_j^t| > \lambda$, the intolerance value will: (1) increase if the neighborhood percentage is larger or (2) decrease if the neighborhood percentage is smaller. The way that the intolerance changes in response to neighborhood composition is outlined in Table 2.

An agent's reactions to it's given surroundings will be given by the cubic function $f(\%_j^t, I_j^t)$, illustrated in Fig 2. I define $f(\%_j^t, I_j^t)$ as follows,

$$f(\%_j^t, I_j^t) = (\%_j^t - I_j^t)\left(1 - \left(\frac{\%_j^t - I_j^t}{\lambda}\right)^2\right). \tag{1}$$

Table 2. How the reaction function $f(\%_j^t, I_j^t)$ works. Non-boundary cases are illustrated in this table. If the absolute difference between the actual neighborhood composition and the desired neighborhood composition (intolerance) is smaller than the conformity then the change intolerance has the same sign.

Sign of $\%_j^t - I_j^t$	$\lvert\%_j^t - I_j^t\rvert < \lambda$ or $\lvert\%_j^t - I_j^t\rvert > \lambda$?	**Sign of $f(\%_j^t, I_j^t)$**
Negative	Less Than	Negative
Negative	Greater Than	Positive
Positive	Less Than	Positive
Positive	Greater Than	Negative

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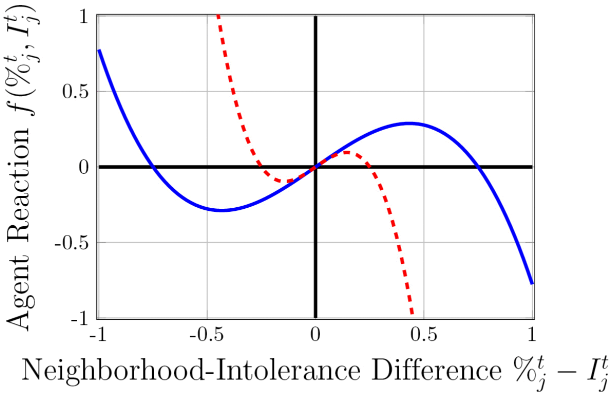

Fig 2. **Sample reaction function.** Two cases of the reaction function, $f(\%_j^t, I_j^t)$ with different conformity values: $\lambda = 0.25$ (red, dashed) and $\lambda = 0.75$ (blue, solid).

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We alter the reaction function so that intolerance values are kept within the range $I_j^t \in [0, 1]$ by multiplying $f(\%_j^t, I_j^t)$ by $I_j^t(1 - I_j^t)$. This gives the final expression for the change in intolerance due to intergroup contact ΔI_j^t,

$$\Delta I_j^t = I_j^t(1 - I_j^t)f(\%_j^t, I_j^t) = I_j^t(1 - I_j^t)(\%_j^t - I_j^t)\left(1 - \left(\frac{\%_j^t - I_j^t}{\lambda}\right)^2\right). \quad (2)$$

Since intolerance values are bounded within the range $I_j^t \in [0, 1]$, the magnitude of the differences between intolerance and neighborhood composition cannot be larger than 1 and hence the conformity values are bounded within the range $0 < \lambda < 1$ through each simulation. We present two examples of ΔI_j^t in Fig 3 when $\lambda = 0.75$ (blue, solid) and $\lambda = 0.25$ (red, dashed) assuming that 50 percent of the i^{th} agent's neighborhood is of the same type as agent j (i.e, $\%_j^t = 0.5$).

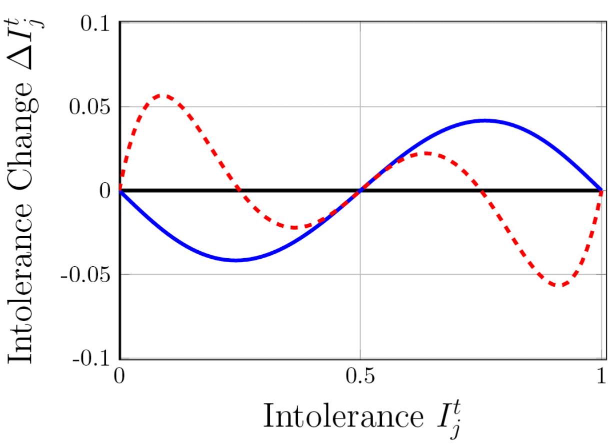

Fig 3. **Example change function.** The change in the tolerance value ΔI_j^t given by Eq. is plotted here. Here, half of the i^{th} agent's neighborhood is composed of individuals from its own group, i.e., $\%_j^t = 0.5$. The conformity values are set to $\lambda = 0.25$ (red, dashed) and $\lambda = 0.75$ (blue, solid).

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Finally, we introduce a timescale parameter τ, termed the **adaptability**. This parameter scales ΔI_j^t and serves to reduce the simulation time. We investigated the effect of **adaptability** on the simulation results in the S1 File. We found that increasing the **adaptability** reduces simulation time while having a negligible effect on the equilibrium values. For all experiments presented, we set $\tau = 20$.

Media effect

Media bias towards certain groups of people is a common phenomenon. Black and Latin individuals in America are overly represented as criminals in media and White individuals are overly represented as upholders of the law [29]. Additionally, Shaver et al. [21] found that increased news consumption was associated with a general decrease in warmth towards Muslims, and this negative relationship did not consistently vary with political ideology.

While media can reinforce long-held biases, it can also be a factor in bias reduction. For example, work by Murrar and Baurer [30] provided evidence that exposure to a sitcom with a diverse set of Arab and/or Muslim characters led to lower levels of prejudice compared to a control group that watched an all-white sitcom. In a field experiment in Rwanda, Paluck [31] exposed participants to a radio program featuring a fictional Rwandan history with a cross-community love story. This was compared to a control group that listened to an existing radio program focused on sexual health and wellness. Finally, a meta-analysis by Saleem et al. [32], encompassing 60 studies from 49 articles, found that negative media exposure is associated with an increase in prejudice against minority groups, whereas positive exposure is associated with a reduction in prejudice. Importantly, the effect sizes were of similar magnitude for both positive and negative media.

We implement the effect of this bias on the i^{th} agent's intolerance as a multiplicative factor, $g(j)$, in the following fashion

$$I_j^{t+1} = (1 - g(j))(I_j^t + \Delta I_j^t). \tag{3}$$

If $0 < g(j) \leq 1$, the agent is consuming **positive (tolerant)** media about the outgroup and hence their intolerance is decreasing. If $g(j) < 0$, the agent is consuming **negative (intolerant)** media about the outgroup and hence their intolerance is increasing. Finally, if $g(j) = 0$, the media is **neutral** and thus their intolerance does not change. It is important to note also that the media effect modulates the impact of an individuals local neighborhood change as well (as $g(j)$ is implemented as a multiplicative rather than additive effect). If not explicitly stated, we will set $g(j) = 0$.

We employ a uniform media consumption pattern for all agents within a specific type. This modeling simplification enables us to focus on the effect of the type of media (negative or positive) consumed. Investigating a more heterogeneous media distribution across the agent population is a valuable direction for future analysis, but preliminary investigations demonstrated that small variation in media consumption in agents do not significantly affect the results presented in the paper.

Simulation algorithm

We now present the full simulation algorithm:

1. Populate the grid according to **density** and **red-percent**. Then execute the following steps:
2. If agents are not satisfied move to an empty grid space that satisfies their intolerance levels.
   i. If there is no empty space that will satisfy them, move to an empty space with a composition closest to their intolerance levels.
3. A random number from 0 to 99 is drawn to determine if an moves according to **non-racial-move**. If the random number is below **non-racial-move** the agent will move to a random empty space.
4. Agents adjust their intolerance according to the rule: $I_j^{t+1} = (1 - g(j))(I_j^t + \Delta I_j^t)$.
5. If the timestep is greater than or equal to 100 then check if last 100 values of **percent-similar** have a standard deviation of 1 and the last 100 values of average intolerance $\overline{I^t}$.

6. Increment timestep by 1.
7. Repeat steps 2 through 7 until simulation stops.

Results

Conformity

We investigate how the agents' conformity affects equilibrium values for segregation. In the following simulations, we set the split between the groups to be 50-50, the **non-racial-move** probability to 5 percent and the **density** to 87.5 percent. Density has a small negative relationship with **percent-similar** for the range we tested (50 to 99 percent). We present the experiment that demonstrates this relationship in the S1 File.

The effect of conformity λ on segregation is given in panel (a) of Fig 4. For any initial value of intolerance small values of conformity lead to integrated equilibria. Integration persists until a critical level of conformity, $\lambda^*(I^0)$, that depends on the initial intolerance. This threshold appears to be nonlinear in nature when starting in a random configuration.

We performed the same experiment with a completely segregated initial condition. This segregated initial condition was generated by spawning all red agents at the bottom of grid and then spawning green agents above the red agents. This threshold becomes linear, $\lambda^* = 0.99 - I^0$ when the simulation starts in completely segregated state. The heatmap demonstrating these results are shown in Fig 5.

The reason why the relationship is linear is because agents initial neighborhood configuration is $\%_j^0 = 1$ for all j aside from the ones at the boundary of the red and green agents for both kinds of agents. This means that if $|1 - I^0| > \lambda$ then the most agents will have an adverse reaction to the segregated condition and their intolerance will decrease. Since there are only random swaps at the beginning many agents will spend time in relatively segregated neighborhoods, leading to a further decrease in intolerance. Then, the random movement mixes the population resulting in an integrated equilibrium.

The final average intolerance of the agents match the segregation results. When $\lambda < \lambda(I^0)$ the intolerance drops near zero and will accept neighborhood composition, matching the integrated state. When λ is above this threshold the agents desire neighborhoods composed purely of their own kind. Therefore, segregation develops when individuals largely conform to their surroundings and integration develops when individuals do not readily conform to their surroundings.

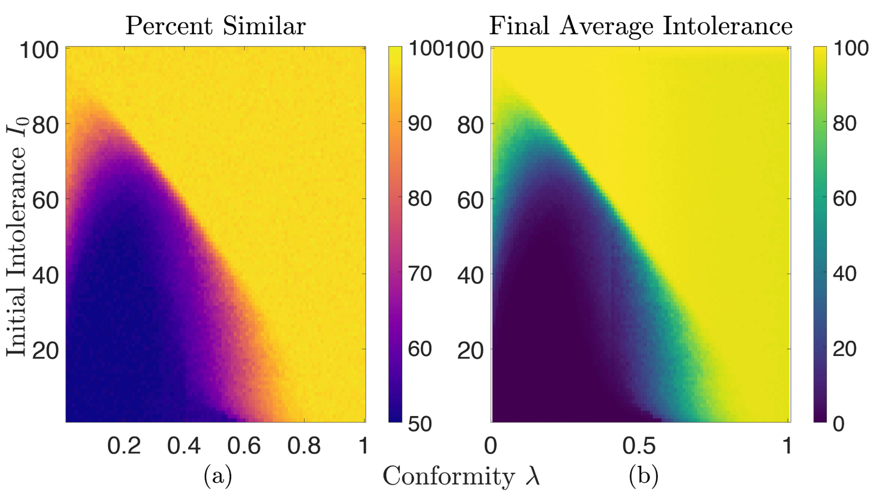

Fig 4. Heatmap of Segregation and Average Final Intolerance. (a) Equilibrium values of segregation measured by percent-similar, and (b) final average intolerance as the conformity λ and initial intolerance I^0 varies. For all values of I^0, fully segregated equilibria occur for past some threshold $\lambda^*(I^0)$. Integrated equilibria occur when conformity values below $\lambda^*(I^0)$. Here, **red-percent** = 50, **density** = 0.875, and **non-racial-move** = 0.05.

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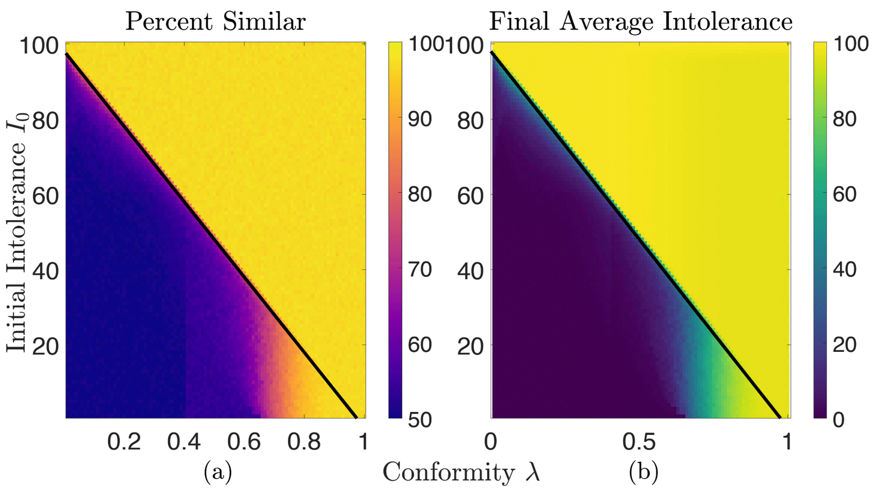

Fig 5. **Heatmap of Segregation and Average Final Intolerance for Segregated Initial Condition.** (a) Equilibrium values of segregation measured by percent-similar, and (b) final average intolerance as the conformity λ and initial intolerance I^0 varies. Agents start in a segregated state, silo-ed in neighborhoods of all red agents or all green agents (except for agents at the boundary). For all values of I^0, fully segregated equilibria occur for past some threshold $\lambda^*(I^0) = 0.99 - I^0$ (black line). Integrated equilibria occur when conformity values below $\lambda^*(I^0)$. Here, **red-percent** = 50, **density** = 0.875, and **non-racial-move** = 0.05.

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Population ratio

We next investigated whether the results of the previous section are robust to differences in the population ratio of agent types. In real world settings, populations are often not equally sized, but rather there may be differing population sizes that can affect the patterns of segregation observed [33,34]. We evaluated whether the results of the previous subsection are robust as the population ratio varies. In the following simulations we set the initial intolerance to $I^0 = 25, 50$.

The effect of population ratio is illustrated in Fig 6. An imbalanced population ratio leads to an increase in segregation. This result is not surprising as the even when agents are placed randomly there is a larger chance for an agent from the larger group to have neighbors from the same group.

As shown in Fig 4 the threshold for the transition to a completely segregated state when $I^0 = 25, 50$ is $\lambda \approx 0.75$ and $\lambda \approx 0.5$ respectively. Panels (a) and (b) demonstrates that this conformity threshold is consistent for all population ratios. Therefore while the population ratio affects the degree of integration/segregation for lower conformity levels, the population ratio does not affect where the transition to completely segregated occurs.

Media influence

Next, we examined the effect that media has on the development of segregation. In this section, we explore adjusting the media influence values $g(j)$ for both the red and green populations to see the effect that purely positive (tolerant) and purely negative (intolerant) media has on segregation. Additionally, we investigate the effect that heterogeneous media consumption (one population consuming negative media and the other positive, and vice-versa) has on segregation.

We analyze the effect of media influence $g(j)$ on segregation and average intolerance. In the following simulations, here we set the media value to $g(j) = g_R$ for red agents and $g(j) = g_G$ for green agents. We set the initial intolerance to $I^0 = 50$ in across all following runs. The population is split evenly between red and green agents and the **density** is set to 87.5 percent.

The effect of media influence on segregation and intolerance is given in Fig 7. Integration develops when at both group's media is positive ($g_G > 0$ and $g_R > 0$). We can investigate further and check how this result changes if we change

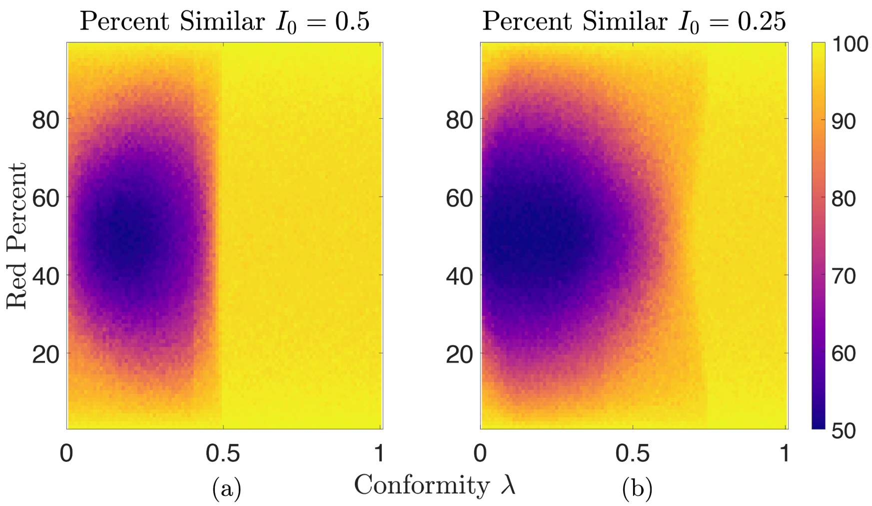

Fig 6. The effect of Population Ratio on Segregation. Equilibrium values of segregation measured by percent similar as the percent of red agents and conformity λ varies for initial intolerance values $I^0 = 25, 50$. As the population becomes more imbalanced the amount segregation rises. Furthermore, the threshold into a fully segregated equilibrium is consistent across all population ratios. These thresholds can be matched to the thresholds in panel (a) of Fig 4. The parameters for the simulations pictured above are $I^0 = 50$, **density** = 0.875, and **non-racial-move** = 0.05.

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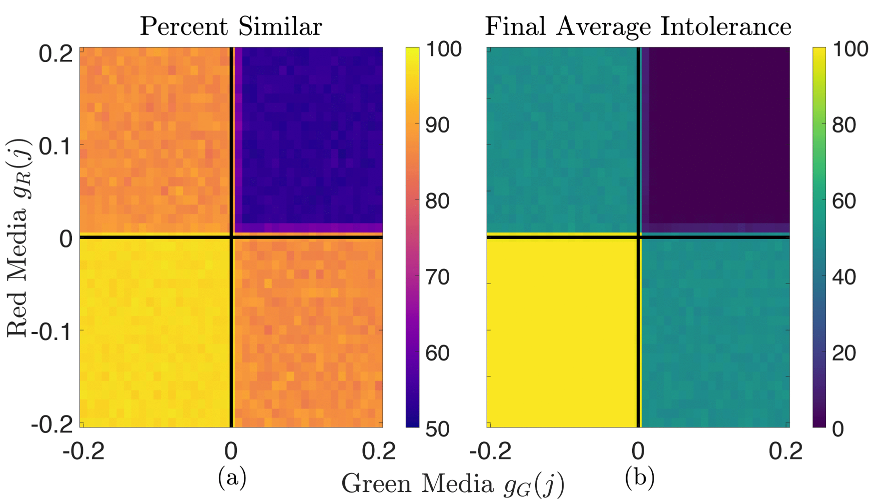

Fig 7. Media Effect on Segregation and Intolerance When $\lambda = 0.5$. Equilibrium values for (a) segregation and (b) final intolerance. When the media values for both the red and green populations consume tolerant media, the integrated equilibrium arises and the intolerance levels approach zero. Here, $I^0 = 50$, **density** = 0.875, and **non-racial-move** = 0.05.

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the conformity value. We set the conformity value at two values clearly below and above the threshold for initial intolerance $I^0 = 50$ given by Fig 4. In the following simulations we set $\lambda = 0.25, 0.75$.

The integrated equilibria persists even when both populations consume negative media when $\lambda = 0.25$ as seen in panel (a) of Fig 8. Furthermore, transition from an integrated equilibria to a segregated equilibria is far smoother when compared to the case when $\lambda = 0.5$ or $\lambda = 0.75$. This demonstrates that when agents do not broadly conform to their neighborhood integration can persist in the presence of negative media. Panel (b) illustrates the case when $\lambda = 0.75$. Here, the

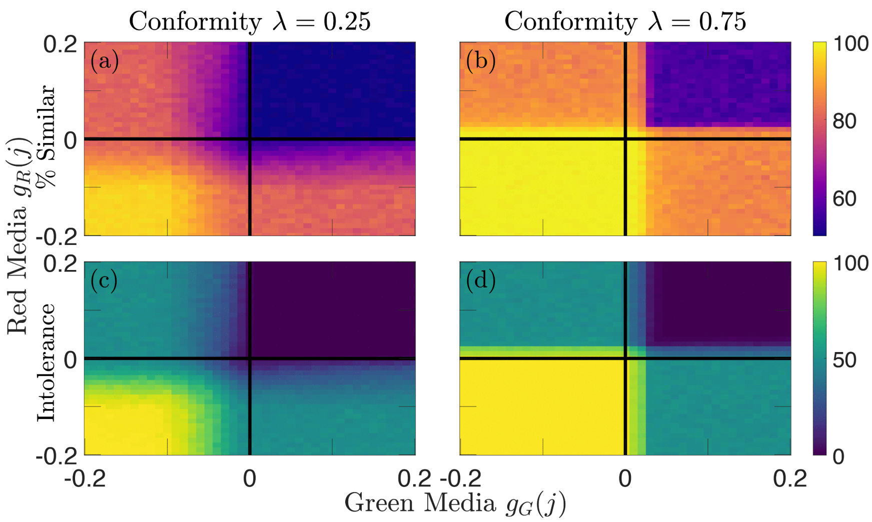

Fig 8. **Media Effect on Segregation and Intolerance for Conformity Values** $\lambda = 0.25, 0.75$**.** Panel (a) and (c) show the equlibrium segregation and the equlibrium average tolerance when the conformity is 0.25. As seen in Fig 4, when both sets of agents consume neutral media then the equilibrium is an integrated state. This lower value of conformity also allows mitigates the effect that intolerant media has on equilibrium segregation.

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segregated state can occur even when both groups are consuming positive media. So, it appears that larger values of conformity reduce the effectiveness of positive media to develop integration.

Non-racial-move probability

Throughout the previous simulations we set an agent's chance to move for reasons outside of it being unsatisfied with its neighborhood composition to five percent. In this section, we vary the non-racial-move probability to explore the affect moving for reasons outside of neighborhood composition has on segregation and intolerance. In the following simulations, the agents' initial intolerance value are set to $I^0 = 50, 25$ and the density is set to 87.5 percent. In the following simulations we vary the non-racial-move probability from 0 to 100.

As illustrated in Fig 9, increasing non-racial-move probability reduces segregation. Panels (a) and (b) demonstrate that the conformity threshold marking the transition from the segregated state to the integrated state demonstrated in Fig 4 is consistent across all nonzero values of non-racial-move probability. The transition at this threshold becomes less stark as one increases the non-racial-move probability until it is imperceptible.

Note, the bottom row of the heatmap give the results of simulation when there is no random movement. This implies that introducing randomness into simulation regardless of how small changes the results. There is a negative relationship between non-racial-move probability and segregation, there is not a notable difference in the equilibrium for small values of non-racial-move probability (1 to 10 percent). Therefore, setting the non-racial-move probability to five percent does not have a perceptible effect.

Discussion

In this paper, we extended Schelling's Model to include sociological factors that could lead to integration, such as inter-group contact, media influence, or movement due to factors outside of neighborhood composition. Within our framework, we demonstrated that integration develops when conformity is low—i.e. when individuals tend not to not to adapt their preferences to their neighborhood population. The conformity threshold is dependent on the society's initial intolerance

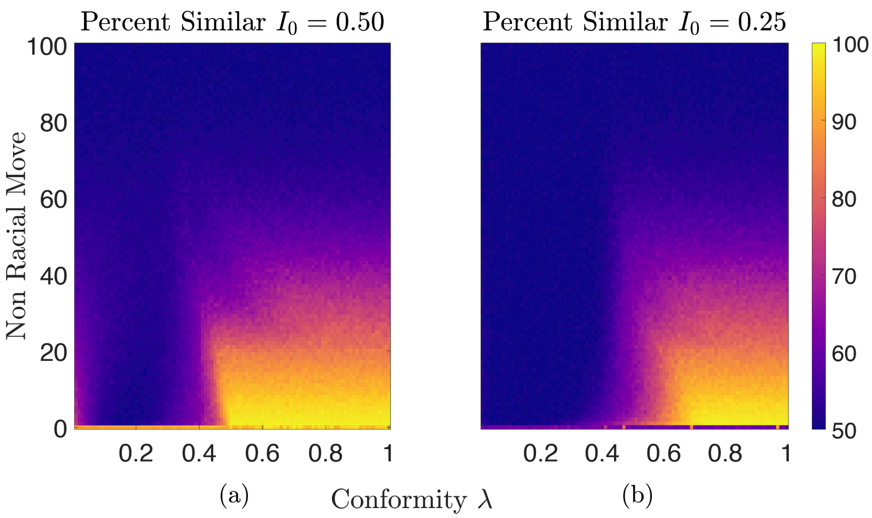

Fig 9. **The Effect of Moving Due to Non Neighborhood Factors.** Equilibrium segregation and final average intolerance values given the conformity λ and probability of moving due to non racial factors when the initial intolerance is (a) $I^0 = 50$ and (b) $I^0 = 25$. The bottom row gives the equilibria with no random movement. The results are distinct from the rest of the simulations that include randomness.

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(e.g. perhaps reflecting the potential effect of previous history on current patterns), however when the agents broadly conform to their neighborhood composition segregated equilibria arise regardless of their initial intolerance. This threshold appears whether the initial state is well-mixed or segregated, although when the initial state is segregated relationship between the critical value of the conformity and initial intolerance appears to be linear.

We found that when both groups consume media that paints the out-group positively segregation is eliminated. When agents broadly conform to their surroundings, segregation can persist even when both groups consume positive media—up to a certain threshold. When agents are broadly repelled by their neighborhood composition, integration seemingly persists even when both groups consume negative media until a critical threshold. We also note that adding in a relatively small amount random movement can lead to integration if conformity is below a critical threshold.

There are several improvements that can be made to this model. This model does not attempt to integrate the conditions laid out by Allport for when intergroup contact leads to reduction in prejudice—equality in status, groups having common goals, and mechanisms assisting in intergroup contact—rather these conditions are assumed to already be in place. Another step in this research will be investigating loosening this assumption and exact how it effects the power of contact to affect intolerance. It would also be of interest to collect more explicit data on ethnic housing preferences and how contact would affect those preferences. Additionally, the status of social groups may influence the frequency and potential benefit of intergroup contact. Finally, we made the choice to make media consumption be homogeneous across agent groups. Investigating how different kinds of heterogeneity can lead to differing equilibrium conditions would be an improvement to the analysis. We leave these alterations to the model for further research.

Future studies would benefit from investigating how incorporating physical or sociological elements, such as physical barriers or exclusionary residential areas, affects segregation dynamics. Such elements represent active, structural drivers of segregation, analogous to historical practices like redlining or the construction of highways to divide ethnic neighborhoods. Integrating these structural factors into the model would provide a more complete understanding of how segregation develops and how it might be mitigated.

Within our framework, it appears that how willing people are to conform is the critical component in the formation of segregation. This might point to a further analysis of the kinds of people who choose to self-segregate and the various methods of altering people's desire to conform so that integration can develop. Furthermore, our work suggests that focusing our supplying positive media of ethnic groups would lead to positive steps in moving toward an integrated populace. We hope that our work leads to more investigation into factors that could drive the population into a more integrated society.

Supporting information

S1 File. Sensitivity Analysis and Evaluation of the Stopping Condition.
(PDF)

Author contributions

Conceptualization: Joseph Davis Johnson, Marisa C. Eisenberg.

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Investigation: Joseph Davis Johnson.

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Visualization: Joseph Davis Johnson.

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Writing – review & editing: Joseph Davis Johnson, Marisa C. Eisenberg.

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