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Abstract

This article uses evolutionary game theory to reveal the interpersonal and geographic characteristics of a society that make it vulnerable to a conquest from within by terrorist organizations and genocide architects. Under conditions identified in the space-less version of the model, entrepreneurs of violence can create the social metamorphosis of a peaceful people group into one that supports or does not resist violence against an out-group. The model is extended into geographic space by analyzing interactions among peaceful and aggressive phenotypes in Moore and von Neumann neighborhoods. The model also reveals policy interventions in which the social evolution of aggression never gets started or comes to a halt if already underway.

JEL Classification Codes: C73, D74, H56

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1. Introduction

Breeders artificially select animal traits by manipulating the animals' DNA, interactions with other animals (e.g., mating, artificial insemination), and environment (e.g., diet, healthcare). In so doing, the breeders create animal phenotypes (traits) that they deem desirable. The evolution of the animals is relatively quick, brought about as it is, not by natural selection, but by artificial selection. Metaphorically, the leaders of terrorist organizations and the architects of genocide seek to "breed" certain types of social outcomes by artificially manipulating peoples' interactions with each other and the environments (perceptions of history, culture, etc.) in which they live. The social outcomes that the violence entrepreneurs seek to engineer are those that advance their tactical and strategic objectives. For example, at the time of this writing, the Islamic State (IS) (formerly known as the Islamic State in Iraq and Syria or ISIS) has unleashed brutalities on civilians in parts of Syria and Iraq including mass executions, torture, and beheadings. Such ruthless actions are often on public display, which serves to intimidate people into supporting, or not resisting, IS' rapid conquest and control of territory. Those who seek to instill peace also seek to engineer social outcomes. Strategic interactions between violence entrepreneurs and third-party violence preventers occur in the context of a malleable and dynamic social context in which the people within such systems also act according to their interests. Given the metaphor between animal breeding and social system breeding, much of the mathematical machinery of evolutionary theory can be adapted to the study of the social evolution of violence and peace. In this article, we take selected aspects of evolutionary game theory dynamics to model how terrorist leaders and genocide architects can artificially manipulate a social environment to advance their objectives of isolating and destroying people from an out-group. We apply evolutionary mathematics to social evolution as distinct from biological evolution.

The article has three objectives. First, we use evolutionary game theory to identify the characteristics of a society that make it vulnerable to a conquest from within by atrocity entrepreneurs (section 2). Under certain conditions, atrocity entrepreneurs can create the social metamorphosis of a peaceful people group into one that accepts or does not resist aggression against an out-group, which we call the "social evolution of aggression." Second, we extend the analysis into geographic space by modeling interactions among peaceful and aggressive phenotypes in two types of geographic areas: Moore and von Neumann (section 3). Third, we analyze policy interventions in which the social evolution of aggression never gets started or comes to a halt if already underway (section 4). We conclude with ideas for future research on modeling the social evolution of aggression and a summary of key results (section 5).[1]

2. Evolutionary Game Theory Model of the Social Evolution of Aggression

We take as given a terrorist organization's or genocide regime's objective to intentionally target civilians for destruction. Outside of weapons of mass destruction, atrocity entrepreneurs cannot pull off large-scale civilian killings on their own. Hence, they need to enlist and train a relatively large number of "willing executioners," which in turn requires social settings (communities)

[1] Evolutionary game theory models that encompass conflict and cooperation can be found in most game theory textbooks as well as in textbooks in biology that contain mathematical methods (e.g., Harrington 2008, Dixit et al. 2013, and Nowak 2006). Most evolutionary games in such textbooks assume that agents are genetically predisposed to display certain traits and that various traits are favored or disfavored over time and correspondingly increase or decrease in the population over many generations. Applications of evolutionary methods in the specific contexts of terrorism and genocide with a focus on social evolution are relatively scarce in the defense and peace economics literature. Two important social evolutionary contributions in the terrorism literature, however, are Arce and Sandler (2003, 2009), who model dynamic social interactions between fundamentalists and non-fundamentalists within a population. Arce and Sandler identify conditions within the models in which non-fundamentalists fake the fundamentalist phenotype in order to do well within a fundamentalist-dominated group. The models also reveal conditions in which non-fundamentalists who are unable or unwilling to fake the fundamentalist trait can be weeded out of the population. Citation here uses evolutionary game theory to model the social evolution of phenotypes within a village that could either support or resist the aims of genocidal architects. He identifies conditions in which the social evolution between hardliners, bystanders, and resisters tilts in favor of genocide resistance, but also conditions in which the village socially evolves to support the aims of the genocide architects. This article extends citation here's work by considering a wider range of parameter possibilities in the space-less model (but with only two rather than three phenotypes) and by evaluating the implications of social evolution across geographic space.

wherein such recruitment and training can succeed (Goldhagen 1996). The focus of the model that follows is upon such social environments. Using evolutionary game theory, we model the conditions that give rise to atrocity-supporting social environments and how the entrepreneurs of violence can attempt to "socially engineer" such communities.

2.1. Stage Game and Fitness Equations

Imagine a village of 10,000 people. Assume an authority group seeks to perpetrate atrocity against an out-group and would like the village to be supportive of its aggressive aims. Assume the potentially targeted out-group encompasses people who are not part of the 10,000 in the village. Some villagers may already have a latent desire for aggression against the out-group; say there are 1,000 such people (10 percent). Assume the other 9,000 (90 percent) would resist aggression against the out-group *under current social conditions*. As the village is characterized now, it would not be useful to the atrocity architects in perpetrating aggression against an out-group. But can the authority group engineer a social metamorphosis of the village such that it becomes supportive of or not resistant to their aims? Can the turning be accomplished relatively easily? Under certain conditions to be identified, the answer to each question is "yes."

Assume each person in the village has one of two dispositions toward people from the out-group: peaceful (P) and aggressive (A). The villagers are *not* genetically hardwired to one disposition or the other; people have free will, so each is free to *choose* the trait that s/he prefers. Humans are social creatures, so there is a lot of interaction among the people in the village day-by-day. People work with others, buy and sell in the marketplace with others, attend charitable causes and political rallies with others, and recreate with others (e.g., sporting events, picnics, etc.). Assume the game matrix in Figure 1 represents the payoffs to two individuals, Bob (the row player) and Sally (the column player), who interact in the village. Assume that Bob and

Sally each choose the aggressive trait (*A*) and they socially interact over coffee. Based on Figure 1, their interaction leads to payoff *a* for each person. If both display the peaceful (*P*) trait, each would receive payoff *d* from their encounter. If Bob is peaceful and Sally aggressive, Bob would receive *c* and Sally *b* as shown in the lower left cell of the matrix. The obverse interaction is shown in the upper right cell in which Bob receives *b* and Sally *c*.

Figure 1 here

In evolutionary game theory, Figure 1 is the "stage game." It is the matrix that governs the payoffs to individuals in all pairwise social interactions in the village. The payoffs reflect the history, culture, language, and interpersonal norms of people in the village. Although highly simplified, the matrix in Figure 1 is a type of "social genome" for the village. Other villages will have different social genomes and more complex genomes can be represented by more complex stage games. Our village's genome will determine its traits or phenotypes, i.e., the number of people that are aggressive (*A*) and peaceful (*P*) toward an out-group. Moreover, the atrocity entrepreneurs can attempt to engineer the traits of people in the village so that a greater number adopt aggressiveness. In short, the social genome is amenable to manipulation.

In social evolutionary terms, the traits of people – peaceful (*P*) and aggressive (*A*) – can be thought of as strategies that they display in their social interactions with others. Assume for simplicity that people cannot play a mixed strategy in which they choose *P* or *A* with a random device. Assume two people are randomly drawn from the village and paired with one another. The pairing represents a social encounter in the village and the payoff to each individual in the pair is governed by Figure 1. Many such social encounters occur in the village throughout the day and we can construct the expected payoff for each strategy from such an encounter. Let *N* represent the number of people in the village (say N=10,000) and n_A the number who initially choose the aggressive trait (say n_A=1,000). It follows that the number of people in the village initially choosing peacefulness, n_P, is equal to N-n_A (n_P=9,000). Given these initial conditions and assuming an individual can be randomly paired with itself (self-play), the probability that a randomly drawn individual from the village would be paired with an aggressive type is (n_A/N) and with a peaceful type is $[(N-n_A)/N] \equiv (n_P/N)$.[2]

Based on Figure 1 and our foregoing assumptions, the expected payoff to a villager who adopts the aggressive strategy, F_A, in a random pairwise social encounter is:

$$F_A = a\left(\frac{n_A}{N}\right) + b\left(\frac{N-n_A}{N}\right) = a(r_A) + b(1-r_A) \quad , \tag{1}$$

where r_A is the ratio of the number of A-types to the total number in the village ($r_A \equiv n_A/N$). The expected payoff to a villager adopting peace, F_P, in a random pairwise social encounter is:

$$F_P = c\left(\frac{n_A}{N}\right) + d\left(\frac{N-n_A}{N}\right) = c(r_A) + d(1-r_A) \quad . \tag{2}$$

In evolutionary game theory, F_A and F_P are the respective "fitness" of the A and P traits in the village. If aggressiveness is rewarded through, say, advancement in the atrocity leaders organization, self-preservation, family preservation, or loot, then the A trait would be relatively fit. If, however, aggressiveness is shunned and the peaceful trait is held in high esteem, then the P strategy would be relatively fit. Equations (1) and (2) show that each strategy's fitness depends on the proportion of the villagers playing each strategy and the payoffs generated from the various pair-wise social encounters. The average fitness in the village, $\bar{F}$, is:

$$\bar{F} = F_A\left(\frac{n_A}{N}\right) + F_P\left(\frac{N-n_A}{N}\right) = F_A(r_A) + F_P(1-r_A) \quad , \tag{3}$$

where F_i (i=A, P) are given in equations (1) and (2).

[2] Self-play is an assumption that simplifies the probability calculations for random draws without substantially affecting results. Specifically, without self-play, the probability that an A-type individual would be paired in a random draw with another A-type is $[(n_A-1)/(N-1)]$ and with a P-type $[(N-n_A)/(N-1)]$. Self-play allows us to treat these probabilities as (n_A/N) and $[(N-n_A)/N]$, respectively.

2.2. Replicator Dynamics and Evolutionary Stable Strategy (ESS)

In social environments, humans look around and learn from the behavior of others. They observe which traits are rewarded and which are penalized and they tend to choose or mimic traits that are successful. In certain atrocity contexts, people who refuse to support aggression toward an out-group (and thus adopt peacefulness in our model) can be subject to dire penalties including incarceration or execution. In this way, such people are "weeded out."[3] Others may act "as if" they support aggression to save their lives or careers or the lives of family members and friends. In our model we treat such people as adopting the aggressive trait.[4] It is important to keep in mind in the analyses that follow that the fitness of traits, specifically, the incentives people have to adopt fitter traits and shun less fit traits, drives social evolution in the village.

The replicator dynamics in evolutionary game theory are equations that describe how fitter strategies are adopted and less fit strategies fall out of favor over time. Following Nowak (2006), the replicator dynamic in the village is governed by the following difference equation:

$$n_A^{t+1} - n_A^t = n_A^t(F_A - \bar{F}) \quad , \tag{4}$$

where n_A^j is the number of A-types in the village at time j ($j=t+1$, t) and F_A and $\bar{F}$ are given by equations (1) and (3), respectively. We could present the replicator equation for n_P, but since $n_P=N-n_A$ and N is fixed, equation (4) also describes changes in n_P over time. Note in equation (4) that if $F_A > \bar{F}$, aggression (A) will be fitter than average and thus fitter than peacefulness (P). As such, the number of people adopting aggression will rise over time and the number displaying peacefulness will decline. It is this dynamic the atrocity entrepreneurs wish to generate. To

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[3] In this article we do not model the weeding out of resisters from the population.

[4] A model with more than two phenotypes could treat feigning aggressiveness as a third phenotype as in Arce and Sandler (2009). In order to compare and contrast our space-less analyses in this section with social evolution over geographic space in the next section, we assume two phenotypes.

complete the replicator dynamics, let the initial number of villagers adopting aggression be n_A^0 and peacefulness n_P^0. In the numerical example earlier, n_A^0=1,000 and n_P^0=9,000.

Based on the payoff values *a*, *b*, *c*, and *d* in the stage game in Figure 1 and assuming no payoff ties for *a* and *c* as well as for *b* and *d*, there are four possible cases in which the ratio of aggressive types, r_A, is determined as summarized in Table 1 (Nowak 2006, p. 50).[5] In Case 1, the payoffs to aggressive types are low relative to the corresponding payoffs to peaceful types: $a<c$ and $b<d$. Case 1 depicts a simplified "social genome" in which the village's history, culture, religion and so forth imply that aggressiveness is unrewarded relative to peacefulness in pairwise social encounters. For Case 2, $a<c$ and $b>d$. Now the payoff for an aggressive type in a "cross encounter" with a peaceful type is more rewarding to the aggressor relative to what s/he would have achieved had s/he been peaceful ($b>d$). In Case 3, $a>c$ and $b<d$. Relative to Case 1, the payoff to an aggressive type in a "same encounter" with an aggressive type is more rewarding to the aggressor relative to what s/he would have achieved had s/he been peaceful ($a>c$). Finally, in Case 4, $a>c$ and $b>d$. Here the "social genome" implies that the aggressive trait is rewarded relative to peacefulness in pairwise encounters. Such a society would be one in which compliance with the atrocity entrepreneurs would lead to survival, career advancement, and/or material rewards while non-compliance would correspond to the absence of such benefits.

Table 1 here

Figure 2 shows four social evolutionary outcomes that can arise in the model based on the four cases in Table 1. Each panel plots the fitness equations (1) and (2) over the ratio adopting the aggressive strategy, r_A, under the parameter assumptions of the four cases.[6] For

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[5] No payoff ties for *a* and *c* and for *b* and *d* eliminates special cases that are not essential to the article's main points.

[6] Figure 2 and the simulations in this article assume that parameter values are not negative, but this is not necessary. For example, if peaceful types are harmed in interactions with aggressive types, *c* would be negative.

Case 1 ($a<c$ and $b<d$) the upper left panel of Figure 2 shows that peace is fitter than aggression ($F_P>F_A$) for any possible ratio of the population adopting aggression. By equations (3) and (4), any temporarily present aggressive types will be less fit than peaceful types, leading to a decline in the number and ratio of individuals displaying aggression. In Case 1, the equilibrium outcome is $r_A^* = 0$ as shown in the top left panel of Figure 2, which is an evolutionary stable strategy (ESS) because any mutation toward aggression by some in the village will remain less fit than peacefulness. Moreover, if the atrocity entrepreneurs sent aggressive types into the village from the outside in an effort to turn the villagers toward aggression, such an invasion would be ineffective in turning the villagers to aggression given the payoff parameter assumptions of Case 1.[7] In Case 1, peace dominates and the village cannot be turned.

When moving from Case 1 to 2 in Figure 2 (see lower left panel), we increase b and/or decrease d. In Figure 1, such parameter changes represent higher payoffs for A-types in cross encounters and/or lower payoffs for P-types in same encounters, which tilts the outcome away from the dominance of peace in Case 1 to coexistence of peaceful and aggressive types in Case 2. We now have equalized fitness (expected payoffs) at $r_A^* = (b-d)/(b-d+c-a)$ in the lower left panel, which is an ESS because any temporary change in r_A above or below r_A^* leads to aggression being less or more fit than peace, causing r_A to move back toward r_A^*. Moreover, if the atrocity entrepreneurs send aggressive types into the village from the outside in an effort to turn it toward aggression, this would temporarily increase r_A, but it would not increase r_A^*. Thus, such a policy would not alter the coexistence outcome given the parameter values of Case 2.

When moving from Case 1 to 3 in Figure 2 (see upper right panel), we increase a and/or decrease c. In Figure 1, such parameter changes represent an increase in payoffs for A-types in

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[7] The invasion of aggressors would increase the number and ratio of aggressive types, n_A^0 and r_a^0, and increase the village's population, N.

same encounters and/or a decrease in payoffs for P-types in cross encounters. This tilts the outcome away from the dominance of peace in Case 1 to a bi-stable situation in Case 3. We now have equalized fitness (expected payoffs) at $r_A^{critical} = (b - d)/(b - d + c - a)$ in the upper right panel. Such an outcome is *not* an ESS because any temporary increase in r_A above or below $r_A^{critical}$ would lead to aggression being more or less fit than peacefulness, causing a change in r_A toward an extreme outcome. Specifically, if there is a sufficiently large number and thus ratio of aggressive types in the population such that $r_a > r_A^{critical}$, then aggression will be fitter than peacefulness and r_A will grow toward $r_A^* = 1$, which is an ESS. Alternatively, if the village contains enough peaceful types such that $r_a < r_A^{critical}$, then peacefulness will be fitter than aggression and r_A will decline toward $r_A^* = 0$, which is also an ESS. Case 3 shows that the initial ratio of aggressive types is critically important in determining whether the village's social evolution is toward atrocity-supporting aggression or atrocity-resisting peace. If the initial ratio r_A is just below $r_A^{critical}$, social evolution will increasingly reward the peaceful trait (as more villagers adopt peacefulness) until only peacefulness is displayed in the village ($r_A^* = 0$). But suppose from the starting point in which r_A^0 is just below $r_A^{critical}$ the atrocity entrepreneurs bring in a small number of aggressive types from the outside such that the initial r_A is just above $r_A^{critical}$. Now social evolution will increasingly reward the aggressive trait over time until the whole village displays aggressiveness ($r_A^* = 1$). Case 3 shows that when the initial proportion r_A is close to $r_A^{critical}$, a small invasion of aggressive types promoted by the atrocity entrepreneurs can have a dramatic effect in tipping the village away from what would have been the social evolution of peace to the social evolution of aggression. The Case 3 village can be turned.

When moving from Case 1 to Case 4 in Figure 2 (see lower right panel), we increase a and/or decrease c and increase b and/or decrease d. In reference to Figure 1, each of these parameter changes favors the fitness of aggressive relative to peaceful phenotypes. For Case 4 we see in the lower right panel that aggression is fitter than peace ($F_A > F_P$) for any possible ratio of the population adopting the aggressive trait. By equations (3) and (4), any temporarily present peaceful types will be less fit than aggressive types, thus leading to a decline in the number and ratio of individuals displaying the peaceful trait. In Case 4, the equilibrium outcome is $r_A^* = 1$, which is an ESS. Note also that there is no need for the atrocity entrepreneurs to send aggressive types into the village to foster the social evolution of aggression because the village is already (and persistently) turned. In Case 4, aggression dominates peace.

Figure 2 here

2.3. A Numerical Example: Engineering the Social Evolution of Aggression

As a numerical example of how an atrocity entrepreneur can engineer a social outcome that supports aggression against an out-group, assume parameter values consistent with a Case 3 bi-stable outcome: a=2, b=1.5, c=1, d=2, and $r_A^0 = 0.20$ (20 percent). Panel (a) of Figure 3 plots the fitness equations (1) and (2) for these parameters and shows that $r_A^{critical} = 0.33$. Since $r_A^0 < r_A^{critical}$, peacefulness is more rewarding (fitter) than aggressiveness, leading more people to choose peacefulness over time according to replicator equation (4). Hence, r_A declines over time in panel (a) until arriving at the ESS in which all villagers adopt peacefulness ($r_A^* = 0$).

Suppose from the panel (a) starting point of $r_A^0 = 0.20$ in Figure 3, the atrocity entrepreneurs insert enough aggressive types from the outside that r_A^0 rises to 0.25. Such a policy alone is insufficient to turn the social evolution away from peace because $r_A^0 = 0.25$ is less than $r_A^{critical} = 0.33$. But suppose the invasion is coupled with policies that increase payoffs in aggressive/aggressive encounters and reduce payoffs in peaceful/peaceful encounters. Specifically, assume a rises from 2 to 2.2 and d falls from 2 to 1.8. As shown in panel (b) of

Figure 3, the relatively small changes in a and d (10 percent each) cause $r_A^{critical}$ to fall to 0.20. Coupled with the relatively small increase in r_A^0 to 0.25 from the invasion, r_A^0 is now greater than $r_A^{critical}$. Hence, in panel (b), the aggressive trait is more rewarding (fitter) than peacefulness, leading more people to choose aggressiveness over time according to replicator equation (4). As such, r_A increases over time in panel (b) until arriving at the ESS in which all villagers are aggressive types ($r_A^* = 1$).

Figure 3 here

2.4. The Nazi Example: Engineering the Social Evolution of Aggression in Occupied Europe

The payoffs *a*, *b*, *c*, and *d* in the stage game in Figure 1 are the outcomes from social interactions in the village, which are rooted in the village's history, customs, and institutions. The payoffs can be thought of as the village's genomic endowment or heritage. We do not model the origins of the payoffs, but take them as given. In villages influenced or controlled by terrorist groups and genocide architects, the social genome is subject to "social engineering" in which the violence entrepreneurs attempt to foster a social metamorphosis to aggression. Our previous analyses, summarized in Table 1 and Figure 2, show that increases in *a* and *b* and decreases in *c* and *d* move the village from Case 1 in which peace dominates toward Case 4 in which aggression dominates. In moving toward Case 4, the intermediate Case 3 (with high *a* and low *c*) could also be amenable to the social evolution of aggression provided a sufficiently large invasion of aggressors came into the village (see Figure 3). Hence, the violence entrepreneurs would like to increase *a* and *b*, decrease *c* and *d*, and/or insert an outside gang of aggressors into the village. What do these constructs represent in a real-world setting of potential social evolution of aggression? We address this question by presenting selected social evolutionary techniques deployed by the Nazis in the occupied territories of Europe during World War II.

In the foundational book in the field of genocide studies, *Axis Rule in Occupied Europe*, Raphael Lemkin (1944, p. xi and 79) described genocide as a "synchronized attack" designed to destroy the existence of a victim group and replace it with the national pattern of the oppressor. Lemkin (1944, pp. xiii-xiv) identified eight dimensions or "fields" of group destruction:

> [I]n the political field (by destroying institutions of self-government and imposing a German pattern of administration, and through colonization by Germans); in the social field (by disrupting the social cohesion of the nation involved and killing or removing elements such as the intelligentsia, which provide spiritual leadership…); in the cultural field (by prohibiting or destroying cultural institutions and cultural activities; by substituting vocational education for education in the liberal arts, in order to prevent humanistic thinking…); in the economic field (by shifting wealth to Germans and by prohibiting the exercise of trades and occupations by people who do not promote Germanism "without reservations"); in the biological field (by a policy of depopulation and by promoting procreation by Germans in occupied countries); in the field of physical existence (by introducing a starvation rationing system for non-Germans and by mass killings, mainly Jews, Poles, Slovenes, and Russians); in the religious field (by interfering with the activities of the Church, which in many countries provides not only spiritual but national leadership); in the field of morality (by attempts to create an atmosphere of moral debasement through promoting pornographic publications and motion pictures, and the excessive consumption of alcohol).

What occurred in each of these eight fields was a social advancement of people who supported or did not resist the Nazi Program and a social degradation of those who did resist. In the context of the simplified social genome in Figure 1, the Nazis implemented policies that increased payoffs to supporters of aggression when aggressive phenotypes interacted (increase *a*) and aggressive and peaceful types interacted (increase *b*). On the flip side, peaceful types were harmed through policies that decreased payoffs to supporters of peace when peaceful and aggressive types interacted (decrease *c*) and peaceful types interacted (decrease *d*). Furthermore, the Nazis implemented invasions of aggressive types into locales to foster the social evolution of aggression. Table 2 presents selected Nazi techniques that promoted the social evolution of aggression categorized according to the parameters of the evolutionary game model.

Table 2 here

3. The Social Evolution of Aggression Over Geographic Space

In this section we extend the evolutionary game model of section 2 into geographic space. Specifically, we model how the social evolution of aggression plays out over time and over a village's area. The introduction of geographic space into the analysis shows, among other things, that atrocity entrepreneurs can use geography to accomplish their objectives even under conditions that are not generally supportive of the social evolution of aggression.

3.1. Payoffs from Social Encounters in a Moore Neighborhood

Following Nowak (2006, Ch. 9), assume each individual in the village is situated on a two-dimensional square lattice in which it socially interacts with each of its immediate neighbors. In each time period, each individual receives a payoff based on its interactions with the various neighbors. Moreover, each individual observes the payoffs accruing to each neighbor and then adopts in the next period the trait or strategy yielding the highest payoff in the neighborhood. Figure 4 is an example of such characteristics and is known as a Moore neighborhood. In panel (a) of Figure 4, assume Sally (in the middle of the lattice) initially selects the peacefulness trait

(P) and her eight immediate neighbors in the lattice also choose peacefulness. According to the stage game in Figure 1, the payoff to a peaceful individual in a social encounter with another peaceful type is d. In panel (a) of Figure 4, Sally socially interacts with eight peaceful types in her neighborhood, so she receives a payoff of $8d$. Assuming that there is not a higher payoff than $8d$ in Sally's neighborhood, she will choose peacefulness in the next period, otherwise she will switch to the aggressive trait. Panel (b) of Figure 4 presents a different situation for Sally. Notice that she is now surrounded by five aggressive and three peaceful neighbors. Based on the stage game of Figure 1, Sally receives a payoff of c from each of the five encounters with an aggressive neighbor and d from each of the three encounters with a peaceful neighbor. Hence, her payoff from the eight encounters in panel (b) is $5c+3d$. If we are in a case in which c and d are low relative to a and b, respectively, then some of Sally's aggressive-displaying neighbors will have a greater payoff than Sally. In the next round, Sally will have an incentive to switch to the aggressive trait (perhaps for sake of self-preservation, career advancement, etc.).[8]

Figure 4 here

3.2. Social Evolution of Aggression in a Moore Neighborhood

Here we present several dynamic and spatial simulations of the social evolution of aggression to demonstrate how an atrocity entrepreneur can engineer outcomes that promote the social acceptance of aggression toward an out-group. We begin with parameter values that align with Case 2 in Table 1 and Figure 2 (i.e., $a<c$ and $b>d$) analyzed earlier in which there was a coexistence outcome. Although we tether the spatial model here to parameters associated with the space-less model of section 2, Moore neighborhood social encounters and payoff generations

[8] Although the boundaries of the lattices in Figure 4 would appear to imply that individuals on the edges do not have eight neighbors, simulations of spatial evolution in a Moore neighborhood can wrap such edges around the square to generate a torus. Toroidal geometry implies that each cell in the grid is equivalent to each other cell and each individual has eight neighbors (Nowak 2006, p. 148).

are not the same as the random pairwise encounters of the space-less model. Hence, the results of the space-less and Moore neighborhood models will differ.

Assume *a*=1, *c*=2, *b*=1.5, and *d*=1 in the stage game of Figure 1 and the initial proportion of aggressors is $r_a^0 = 0.20$. Assume the village is made up of 10,000 people (*N*=10,000). Based on simulation techniques available from EvoLudo, panel (a) of Figure 5 shows a 100x100 square lattice in which 20 percent of the village's inhabitants are initially aggressive types (shown by the red cells) and 80 percent are peaceful types (shown by the blue cells) (see evoludo.org). The initial distribution of types is randomly assigned across space by EvoLudo. Panel (b) of Figure 5 shows the period 25 result of the social evolution of phenotypes in the Moore village. The blue cells represent peaceful types who were peaceful in the previous period and the red cells aggressive types who were aggressive in the previous period. The green cells show peaceful types who were aggressive in the previous period. The yellow cells show aggressive types who were peaceful in the previous period. Figure 5 shows the social evolution to a coexistence outcome in which the proportion of people adopting the aggressive trait will oscillate between about 27 and 41 percent even out to thousands of periods. Particular individuals in the village will switch their strategies over time, depending on relative fitness in sub-neighborhoods, but the proportionate outcome remains in the range of about 27 to 41 percent aggressiveness.

Figure 5 here

Assume now that *a*=2, *c*=1, *b*=1, and *d*=2 in the stage game of Figure 1 and the initial proportion of aggressors is $r_a^0 = 0.20$. These parameter values correspond to Case 3 in Table 1 and Figure 2 in the space-less model in which there was a bi-stable outcome. Panel (a) of the *previous* figure (Figure 5) represents EvoLudo's random distribution of the initial 20 percent aggressive types in the village. Panel (a) of Figure 6 shows a quick social evolution to peace in the village by period 2 under our new parameters ($r_A^* = 0$). From panel (a), assume the atrocity entrepreneurs are able to increase the payoff in aggressive/aggressive encounters by 25 percent from *a*=2 to *a*=2.5. Panel (b) shows the implications of the parameter change in the village at period 75. Permanent blocks (sub-neighborhoods) of aggressive types emerge in the village encompassing about 2.8 percent of the population. This may seem relatively benign, but the village is close to a tipping point in which it could evolve to complete aggression. In panel (c) of Figure 6, we go back to the initial conditions of *c*=1, *b*=1, *d*=2, and $r_a^0 = 0.20$, but we increase parameter *a* just a bit more to 2.7. By period 10, aggression has seriously metastasized in the village. By period 23, the village has socially evolved to complete aggression (not shown).[9]

Manipulating *a* is not the only social genomic tool available to atrocity entrepreneurs; parameters *b*, *c*, and *d* can also be manipulated. Assume now that *a* is back to the value of 2.5 in which blocks of aggressive types occur for 2.8 percent of the population as in panel (b) of Figure 6. Let *b* increase by 20 percent from 1 to 1.2 and *c* fall by 20 percent from 1 to 0.8. Parameter *b* is the payoff to an aggressive type in a cross encounter with a peaceful type and *c* is the payoff to a peaceful type in a cross encounter with an aggressive type. These parameter changes tilt the game in favor of aggressors and against peaceful types in cross encounters, everything else the same. Begin from EvoLudo's random distribution of the initial 20 percent aggressive types in the village, such as panel (a) in Figure 5 above. In panel (d) of Figure 6, numerous concentrations of aggressive types socially evolve by period 5. By period 18, the whole village socially evolves to the aggressive phenotype such that $r_A^* = 1$ (not shown). Figure 6 shows how relatively easy it is for atrocity entrepreneurs to put the village on the path toward the social evolution of complete aggression. All that was required was a 35 percent favorable change in

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[9] The time period of convergence and, for some parameter sets, the proportion of phenotypes that persist over time, depend on EvoLudo's random spatial distribution of initial phenotypes.

payoffs to aggressive types in same encounters (increase *a* from 2 to 2.7) or a 25 percent favorable change in same encounters (increase *a* from 2 to 2.5) coupled with a 20 percent favorable change in cross encounters (increase *b* from 1 to 1.2 and decrease *c* from 1 to 0.8).

Figure 6 here

3.3. Payoffs from Social Encounters in a von Neumann Neighborhood

In a von Neumann neighborhood, each player interacts with its four nearest neighbors to the north, south, east, and west and does not interact with its diagonal neighbors. In panel (a) of Figure 4 above, Sally would only interact with neighbors 2, 4, 6, and 8 in a von Neumann neighborhood and thus receive a payoff of 4*d*. In panel (b) of Figure 4, Sally's von Neumann neighborhood payoff would be 2*c*+2*d*. Just like the Moore neighborhood, we assume here that each individual observes the payoffs accruing to each neighbor and then adopts in the next period the trait yielding the highest payoff in the neighborhood.

3.4. Social Evolution of Aggression in a von Neumann Neighborhood

Social evolutionary behaviors in von Neumann relative to Moore neighborhoods can be quite different as demonstrated in Figure 7. In panel (a) we have *a*=2, *b*=1, *c*=1, *d*=2, and $r_A^0 = 0.20$ and EvoLudo randomly distributes the 20 percent red cells across the population such as shown earlier in panel (a) of Figure 5. Recall that for these parameter values in a Moore neighborhood, social evolution quickly converged to complete peacefulness by period 2 (see panel (a) of Figure 6). For the von Neumann neighborhood, however, pockets of aggressors persist in the village encompassing about 2.1 percent of the population by period 10 as shown in panel (a) of Figure 7. Even out to thousands of periods, blocks of aggressive types persist in the von Neumann neighborhood (not shown). Generally, von Neumann geography is more beneficial to aggressive types than Moore geography for equivalent parameter values. For example, in panel (b) of

Figure 7 we show the social evolution in a *Moore village* assuming *a*=2.4, *b*=1.2, *c*=0.8, *d*=2, and $r_A^0 = 0.20$. As panel (b) shows, blocks of aggressive types persist in the Moore village even out to time period 1,000. In the less dense interactions of a von Neumann relative to a Moore neighborhood (4 neighbors rather than 8), however, the same parameter values that converged to a few isolated blocks of aggressive types in the Moore village socially evolves toward complete aggression in the von Neumann village as shown in panel (c). Shown in that panel is the social evolution of aggression at period 100. By period 115, the social evolution is complete and the whole village is made up of aggressive phenotypes (not shown).[10]

Atrocity entrepreneurs can also engineer sub-neighborhoods of aggressors as shown in panel (d) of Figure 7 assuming a von Neumann village. In that panel we return to the parameter values *a*=2, *b*=1, *c*=1, *d*=2, and $r_A^0 = 0.20$. By period 10, persistent blocks of aggressors surrounded by much larger groups of peaceful types emerge (not shown). In the upper left corner of panel (d), we "artificially inseminate" the village with 25 additional aggressors in a concentrated block in a sub-neighborhood of the village. Panel (d) of Figure 7 shows the results at period 50. The artificially created block of aggressive types persists, as do all other aggressive blocks, even though the overall village strongly tilts toward peacefulness. Panel (d) implies that if a particular sub-neighborhood is especially valuable to the atrocity entrepreneurs for achieving their objectives, they can create local "success" given von Neumann relative to Moore geography even when the overall social evolution favors peacefulness.

Figure 7 here

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[10] In footnote 9 we noted that the outcome of a simulation can be sensitive to EvoLudo's initial random spatial distribution of phenotypes. In ten Moore simulations with the parameter values of panel (b) of Figure 7, all converged to the presence of blocks of aggressive types surrounded by mostly peaceful types as shown in panel (b). For ten von Neumann simulations using the parameters of panel (c) of Figure 7, nine converged to complete aggression and one converged to the presence of large blocks of aggressive types (much larger than in panel b for the Moore village). Overall, the von Neumann village is more prone than the Moore village to the survivability and spread of aggressive types for the simulations that we ran, everything else the same.

4. Policy Interventions and the Social Evolution of Peace

At the most basic level, third-party interveners for peace seek to socially engineer the opposite outcome in a village relative to the aims of the atrocity entrepreneurs. In the space-less model in section 3, peace supporters would like a village's "social DNA" to be such that the peaceful trait is rewarded and aggressiveness is unrewarded in pairwise encounters. Hence, if parameters *a* and *b* are relatively low and *c* and *d* relatively high, Case 1 emerges in Figure 2 such that peace dominates everywhere in the village. For less sanguine parameter values, for example those corresponding to the Case 3 bi-stable outcome in Figure 2, the initial number of peaceful types in the village can be critically important in insuring that peace rather than aggression socially evolves in the village. Hence, insertion of peacekeepers can be decisive in insuring peace under certain conditions. When considering geographic space in evolutionary dynamics, additional issues come to the fore for peacekeeping consideration, to which we now turn.

4.1. Policy Interventions for Peace in a Moore Neighborhood

Assume *a*=2.7, *b*=1, *c*=1, *d*=2, and $r_A^0 = 0.10$ in a Moore village. Panel (a) of Figure 8 shows a metastasizing lump of aggressive types by period 3. Left unchecked the lump will grow until the whole village is of the aggressive type (not shown). In panel (b), we insert 15 peacekeepers into the center of the lump. Panel (c) shows that the peacekeeping effort is too little too late. By period 15, the lump has aggressively metastasized and, left unchecked, will evolve until the whole village is aggressive (not shown). Panel (d) shows at period 3 a lump that is the same size as that shown in panel (c). Similar to the lump in panel (a), insertion of 15 peacekeepers will be insufficient to stem the growth of aggression (not shown). Hence, we insert 20 peacekeepers into the lump as shown in panel (e). Panel (f) shows that by period 4 aggression is contained and the village is made up of only peaceful types. What is striking about Figure 8 is how the fate of the village can hang on a "knife edge." With 20 rather than 15 peacekeepers, complete peacefulness is sustained in the village rather than the emergence of complete aggression.

Figure 8 here

Following Nowak (2006, pp. 159-160), we consider the role of "walkers" in creating a "big bang" of peace. A walker is a concentrated unit of 10 peaceful types that operates in a world of aggressive types (Nowak 2006, p. 159). In panel (a) of Figure 9, two walker teams are inserted at time 0 into the otherwise completely aggressive Moore village under parameter assumptions that favor peaceful types in same encounters (*d*=1), aggressive types even more in cross encounters (*b*=1.51), but otherwise are not favorable (*a*=0, *c*=0). The village's population is *N*=4,761, so the 20 peacekeepers imply $r_a^0 = 0.996$.[11] In 100 simulations not presented in this article in which the initial proportion of aggressors was 90 percent and they were randomly distributed in the village, social evolution always converged to complete aggression. But the "walker intervention policy" in panel (a) leads to a decidedly different outcome. By time 6 the walker teams are close to connecting as shown in panel (b). Panel (c) shows the early stage of a "big bang" of peace in period 8. By time 15, the social evolution of peace continues to grow (see panel d). Panel (e) shows that by time 60, peace has become dominant in the village and by time 150, pockets of aggressive types are relatively small and contained as shown in panel (f).

Figure 9 here

4.2. Policy Interventions for Peace in a von Neumann Neighborhood

A von Neumann village is less concentrated than a Moore village in that each individual interacts with four neighbors rather than eight. We ran the same simulations here as in the previous sub-section to compare and contrast policy interventions for peace under the two geographies.

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[11] *N*=4,761 was Nowak's (2006) assumption in his walker analysis, which we follow here.

Assume as above in Figure 8 that *a*=2.7, *b*=1, *c*=1, *d*=2, and $r_A^0 = 0.10$, but now we are in a von Neumann village. In panel (a) of Figure 10, we show the emergence of persistent blocks of aggressive types by period 3. These aggressive blocks will persist out to thousands of periods (not shown). In panel (b), we insert one peacekeeper into the center of each of the 41 aggressive blocks. Panel (c) shows that the peacekeeping effort is effective for those blocks that had five or fewer aggressive types, but ineffective for blocks that had six or more aggressors. Panel (d) of Figure 10 shows at time 3 the insertion of one peacekeeper into aggressive blocks of five or fewer and two peacekeepers into aggressive blocks of six or more. By time 4, the whole village socially evolves to peace (not shown). The spatial dynamics of peacekeeping in Moore relative to von Neumann neighborhoods differ. In Moore neighborhoods, concentrations of aggressive types can begin to socially evolve and peacekeeping efforts must be sufficiently concentrated and substantial if aggression is to be neutralized. In von Neumann geography, however, many scattered locales of aggressive types can persist, even under parametric conditions that overall are supportive of peacefulness. Under such conditions, peacekeeping efforts must be sufficiently disparate (geographically) and substantial per locale for the aggressive lumps to be eradicated.

Figure 10 here

Figure 11 shows that walker peacekeeping efforts differ under von Neumann relative to Moore geography. In panel (a), two peaceful teams of ten are inserted at time 0 into the otherwise completely aggressive von Neumann village under the same parameter values as in the Moore village analyzed in Figure 9 (i.e., a=0, b=1.51, c=0, d=1, and $r_a^0 = 0.996$). The walker intervention policy shown in panel (a) of Figure 11 is the same as that shown in panel (a) of Figure 9, but under von Neumann geography the results are decidedly different. By time 6, the walker teams are close to connecting as shown in panel (b) of Figure 11. Panel (c) shows by time 12 the emergence of, not a big bang of peace, but a "small band" of peace. Running the simulation forward from panel (c)'s time 12 leads to no further changes. Hence, von Neumann geography is not conducive to a big bang of peace the way Moore geography is. Moreover, the big bang of peace under Moore geography required two concentrating teams of walkers. Under von Neumann geography, however, each walker team has the capability of carving out its own small band of peace as shown in panels (d)-(f) of Figure 11. In panel (d), we set the initial teams of walkers such that they will *not* connect. By period 25, each team is carving out its own small band of peace. By about period 75, the creations of the small bands of peace have come to an end, but much of the village remains of the aggressive phenotype.

Figure 11 here

5. Conclusions

People groups are amenable to forms of social genomic engineering in which their interpersonal interactions, perceptions of culture and history, and population mixes are manipulated to support the aims of a small group of "social engineers." In this article, the social engineers are the leaders of terrorist organizations or genocide architects, who seek to socially transform people groups away from peacefulness to an aggressive posture toward out-groups. Using evolutionary game theory models, we analyzed population mixes and how people relate or misrelate to others in space-less pairwise encounters and in Moore and von Neumann neighborhoods to highlight conditions under which atrocity engineers can transform a village into supporting, or not resisting, violence against an out-group. We also analyzed conditions under which peacemakers could prevent the social evolution of aggression.

Future research on modeling the social evolution of aggression should consider that much of the vast array of mathematical machinery in evolutionary biology has yet to be adapted to the study of the social evolution of aggression and peace. Many other neighborhood assumptions beyond von Neumann and Moore can be considered. For example, individuals in a village could be treated as triangular (having three direct neighbors) or pentagonal (having five direct neighbors) and so forth such that a wide range of population densities could be modeled (three, four, five, six direct neighbors, etc.). EvoLudo's simulation techniques already allow very dense neighborhoods of 24, 48, 80, and even higher levels, with results that can vary significantly from the von Neumann (4 neighbors) and Moore (8 neighbors) geographies. Furthermore, in this article we used "best wins equal stay" player updates and synchronous population updates. Numerous other player and population update protocols are available in the evolutionary literature including, for players, "best wins equal random," "best reply," and "Fermi update," and for populations, "asynchronous replication," "birth death processes," and "stochastic updates."[12] Moreover, there are alternative methods for modeling replicator dynamics including alternative replicator equations, variations in the degree to which payoffs translate into fitness, potential for sub-groups of the population to only interact with those they desire, migrations into and out of the population (e.g., births, deaths, refugees), and stochastic elements. In addition, modeling the spatial social evolution of aggression and peace can consider three (or more) phenotypes such as fundamentalists, non-fundamentalists, and feigners (as in Arce and Sandler 2009) or hardliners, bystanders, and resisters (as in citation here). Potentially important geographic elements such as forests, mountain ranges, borders, waterways, and population density variations in sub-neighborhoods could also be incorporated into such models.

The key messages of our article are several. First, under a fairly wide range of conditions, people groups can socially exist near a "knife edge" in which small social engineering efforts toward aggression or peace can have dramatic effects. We saw in several

[12] For summaries of these and other update protocols see Nowak (2006), Hauert (2002), and evoludo.org.

simulations that a small effort to foster aggression by the atrocity entrepreneurs could tip an otherwise peaceful village into a social metamorphosis in which the whole village comes to support aggression. The tipping can go the other way. Relatively small but well-timed and well-located peacekeeping efforts can neutralize the social evolution of aggression and allow peace to persist in a village. The fate of a village can truly hang in the balance between the engineering efforts of atrocity entrepreneurs and peacemakers. Second, geographic space really matters in understanding the social evolution of aggression. Social evolution for highly concentrated people in a Moore village can play out very differently over time and space relative to the less concentrated people groupings in a von Neumann village and relative to space-less models. For example, “walker” peacekeeping interventions in a Moore village can lead to a “big bang” of peace, but the same conditions in a von Neumann village lead to a muted outcome for peace. We also found that the deterministic space-less model leads to definitive outcomes whereas the outcomes in models with geographic space can be sensitive to the initial random spatial distribution of the population mix. Third, under conditions in which the social evolution of aggression can metastasize within a village, *early* and *well-located* (geographically) interventions for peace are essential to stop aggressiveness in its tracks. Fourth, any *general* claims about the ability or inability of peacekeepers to prevent the social evolution of aggression should be looked at with suspicion. Social context is immensely important for understanding how people relate or misrelate to one another and such contexts vary widely across the world and within states, cities, towns, rural areas, and neighborhoods. In some social settings, a small peacekeeping effort can have dramatic effects in fostering a more peaceful social context among people from an in-group. In other settings, the aggressive fate of the village may be sealed and scarce peacekeeping resources might be better deployed elsewhere.

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Figure 1: Payoffs in Pairwise Encounters in the Evolutionary Game Theory Model

		Sally	
		Aggression (*A*)	Peacefulness (*P*)
Bob	Aggression (*A*)	*a*, *a*	*b*, *c*
	Peacefulness (*P*)	*c*, *b*	*d*, *d*

Figure 2: Four Cases in the Evolutionary Game Theory Model

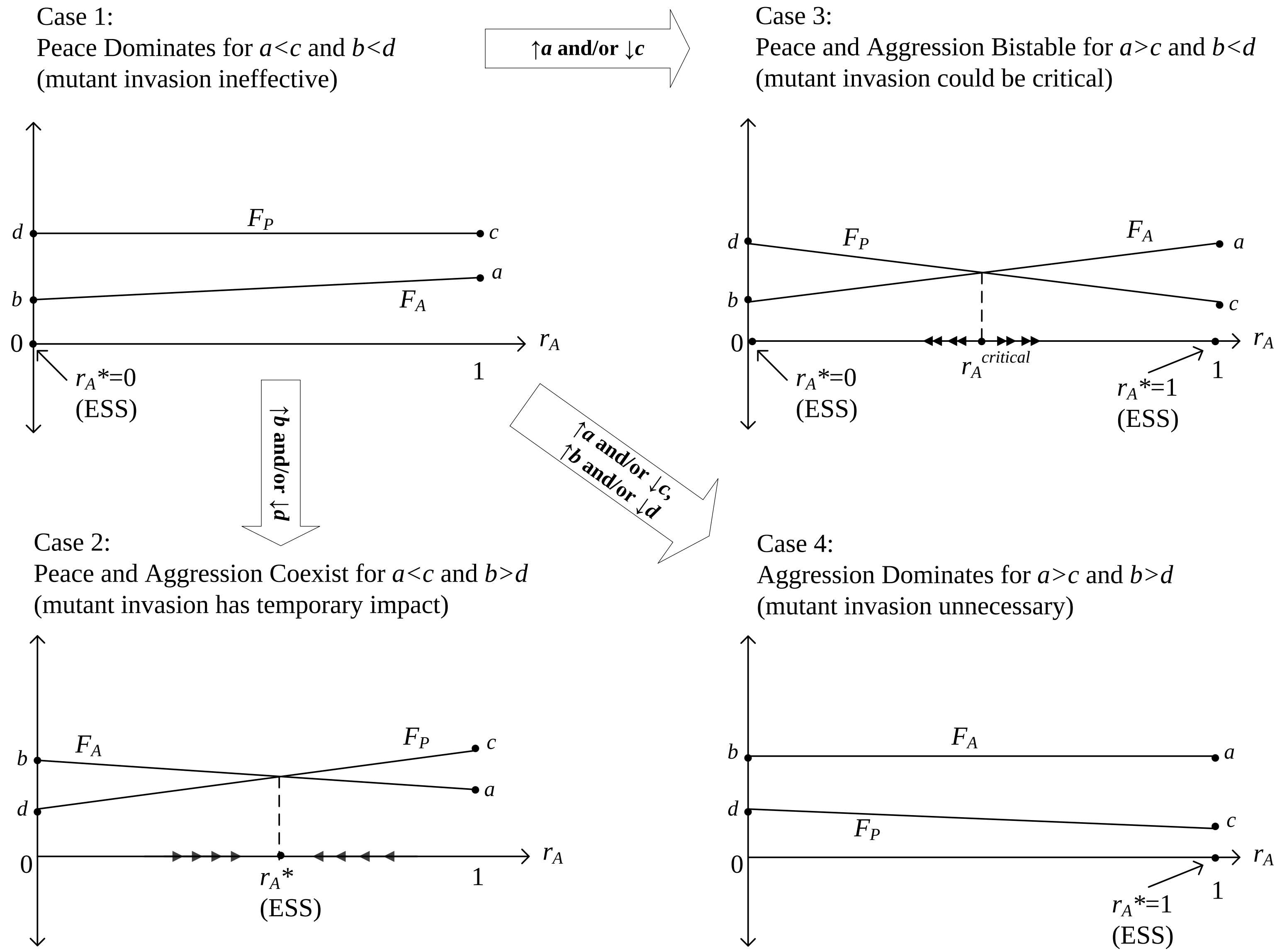
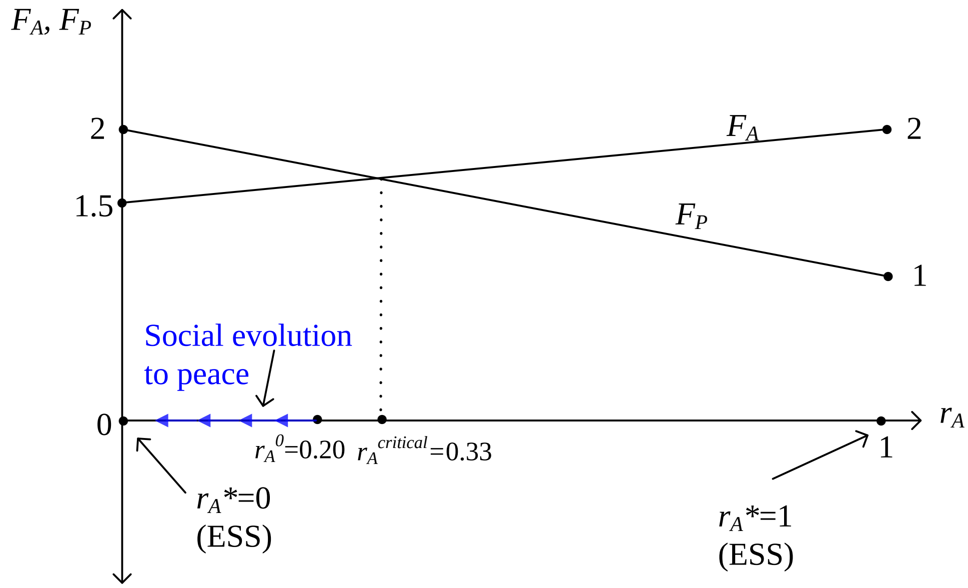


Figure 3: Engineering the Social Evolution of Aggression

Panel (a): Initially $r_A^0 = 0.20 < r_A^{critical} = 0.33$ ➔ peacefulness is fitter than aggression (F_P>F_A) ➔ social evolution over time to ESS at $r_A^* = 0$, which is complete peacefulness.



Panel (b): Increase in r_A^0 to $r_A^{0\,new} = 0.25$ coupled with parameter changes (increase in *a* to 2.2 and decrease in *d* to 1.8) that cause $r_A^{critical}$ to fall to $r_A^{critical\,new} = 0.20$. Since $r_A^{0\,new} = 0.25 > r_A^{critical\,new} = 0.20$, aggression is fitter than peacefulness (F_A>F_P) ➔ social evolution over time to ESS at $r_A^* = 1$, which is complete aggressiveness.

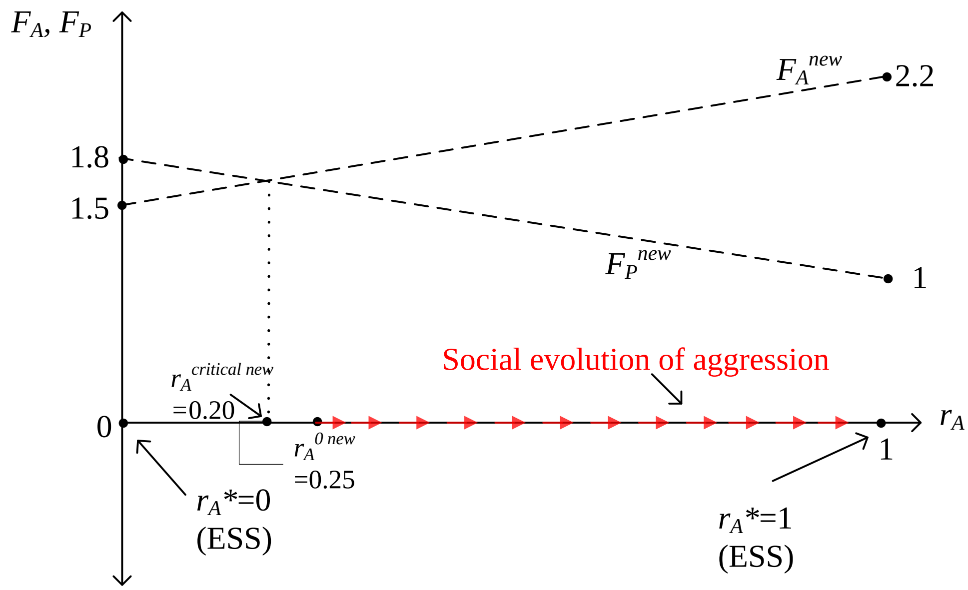
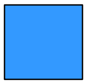
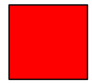


Figure 4: Sally's Spatial Interactions and Payoffs in a Moore Neighborhood

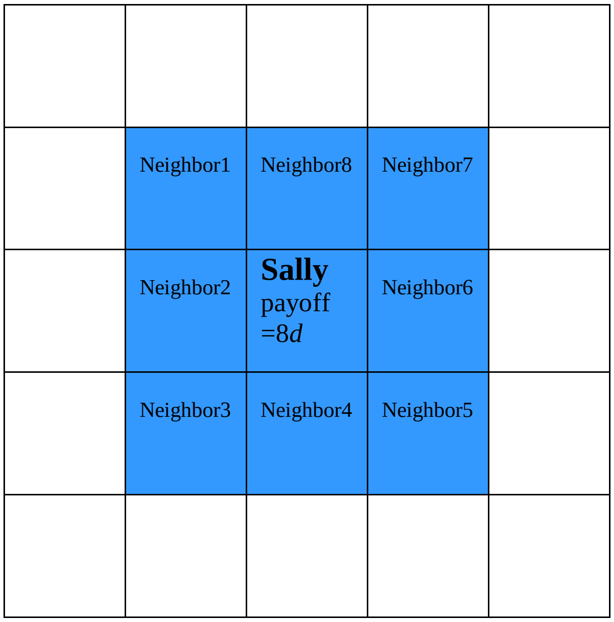


blue cell for person choosing peacefulness (*P*) trait

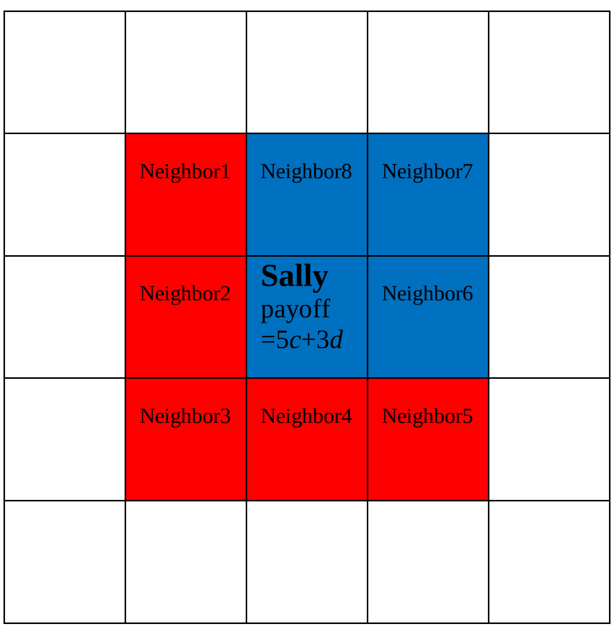


red cell for person choosing aggressive (*A*) trait

Panel (a): Sally chooses peacefulness and has 8 peaceful neighbors ➔ Sally's payoff =8*d*



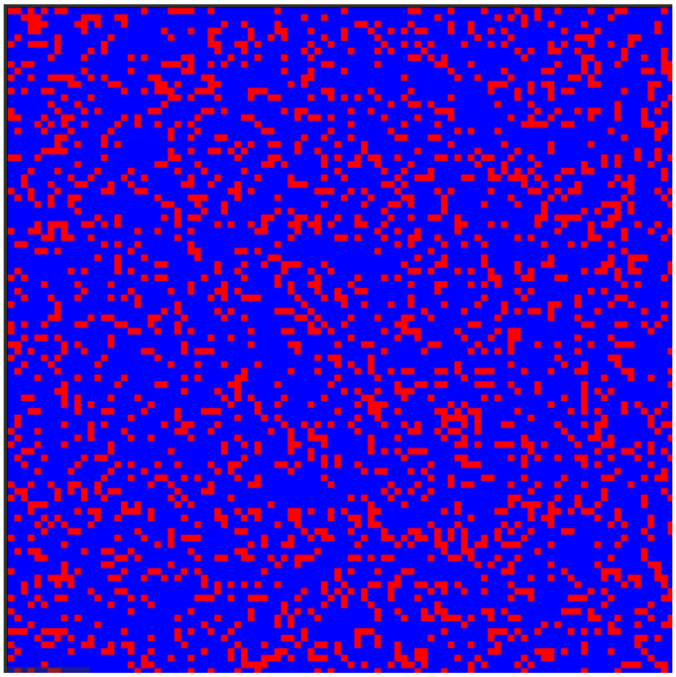
Panel (b): Sally chooses peacefulness and has 5 aggressive and 3 peaceful neighbors ➔ Sally's payoff =5*c*+3*d*



Note:
When choosing peacefulness, Sally's payoff from each peaceful neighbor is *d* and from each aggressive neighbor is *c* based on the stage game in Figure 1.

Figure 5: Social Evolution in the Moore Village (for *a*=1, *b*=1.5, *c*=2, *d*=1, $r_A^0 = 0.20, N = 10,000$, Player updates: best wins equal stay, Population updates: synchronous)

Panel (a): Time period 0 in which 20 percent of village is aggressive type



Panel (b): Time period 25 in which about 40 percent of the village is aggressive type

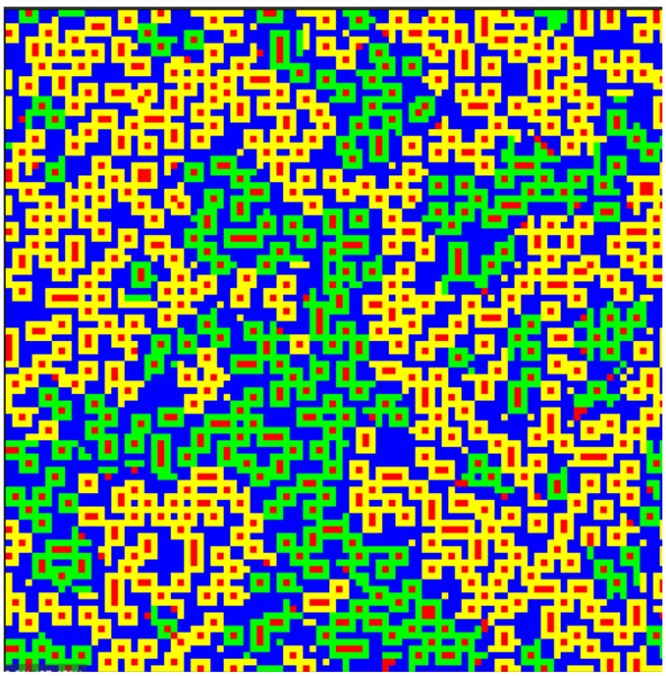
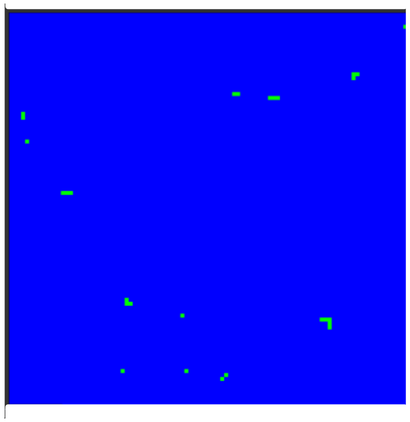
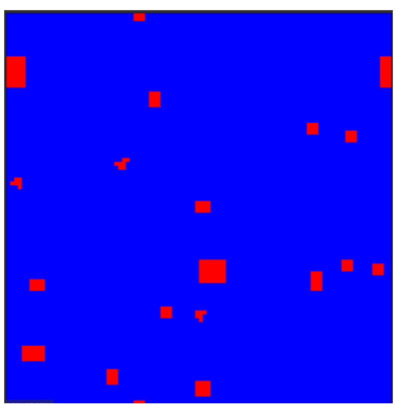


Figure 6: Social Evolution in the Moore Village (initially for *a*=2, *b*=1, *c*=1, *d*=2, $r_A^0 = 0.20$, *N*=10,000, Player updates: best wins equal stay, Population updates: synchronous)

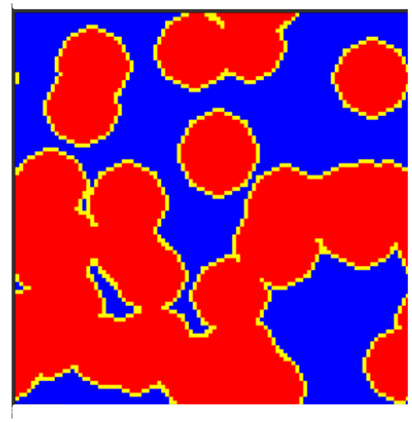
Panel (a): Social evolution to peacefulness by period 2



Panel (b): Increase in payoff in aggressive/aggressive encounters to *a*=2.5 and convergence to 2.8% aggressive types in blocks (period 75)



Panel (c): Increase in payoff in aggressive/aggressive encounters to *a*=2.7, leading to tipping point for social evolution of aggression (period 10)



Panel (d): Social evolution to aggression for *a*=2.5, *b*=1.2, *c*=0.8, *d*=2, $r_A^0 = 0.20$ (period 5)

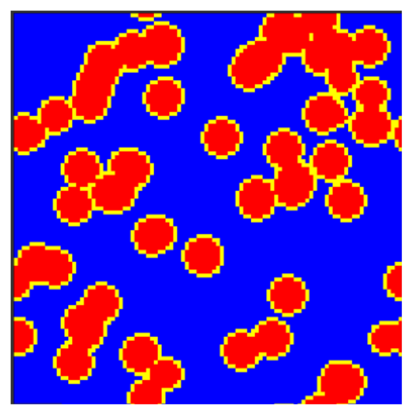
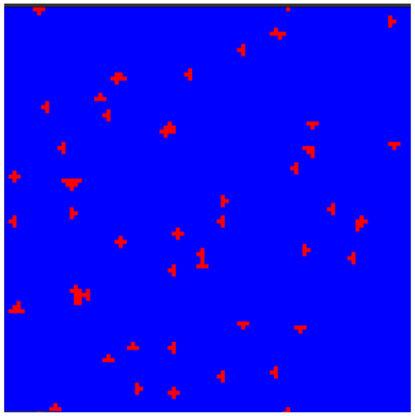
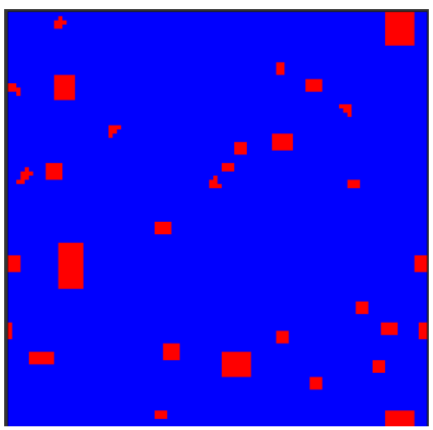


Figure 7: Social Evolution in the von Neumann Village (*N*=10,000, Player updates: best wins equal stay, Population updates: synchronous)

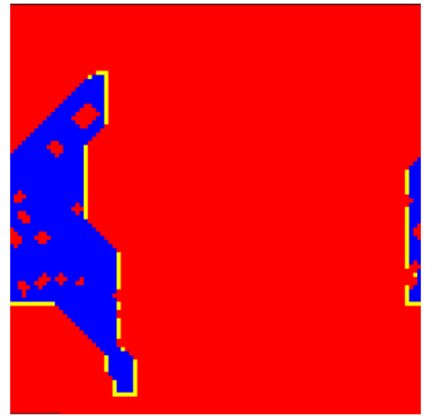
Panel (a): Blocks of aggressive types persist in von Neumann village for *a*=2, *b*=1, *c*=1, *d*=2, $r_A^0 = 0.20$ (period 10)



Panel (b): Blocks of aggressive types persist in Moore village for *a*=2.4, *b*=1.2, *c*=0.8, *d*=2, $r_A^0 = 0.20$ (period 1,000)



Panel (c): Social evolution of aggression in von Neumann village for *a*=2.4, *b*=1.2, *c*=0.8, *d*=2, $r_A^0 = 0.20$ (period 100)



Panel (d): Creation of block of aggressive types in northwest corner of von Neumann village for *a*=2, *b*=1, *c*=1, *d*=2, $r_A^0 = 0.20$. This and other blocks persist (period 50)

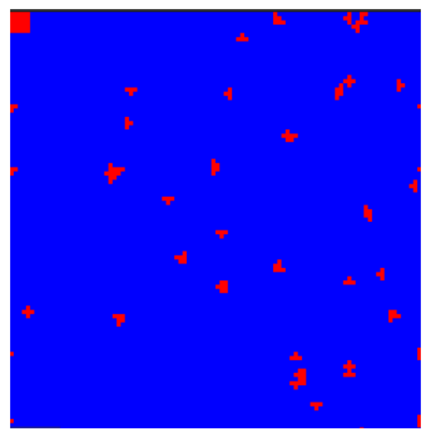
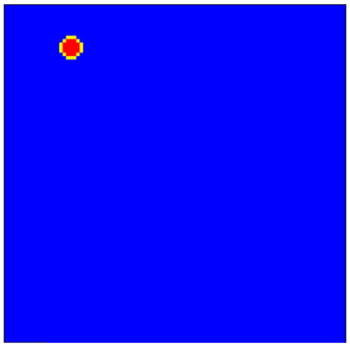
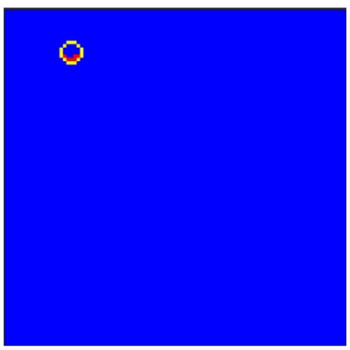


Figure 8: Peacekeeping and the Fate of the Moore Village (*a*=2.7, *b*=1, *c*=1, *d*=2, $r_A^0 = 0.10$, *N*=10,000, Player updates: best wins equal stay, Population updates: synchronous)

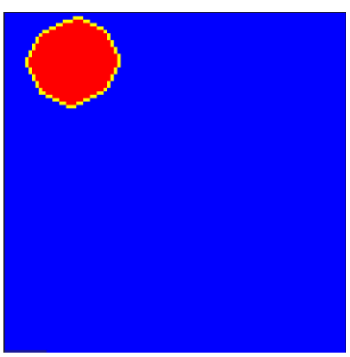
Panel (a): Lump of aggressive types emerges (period 3)



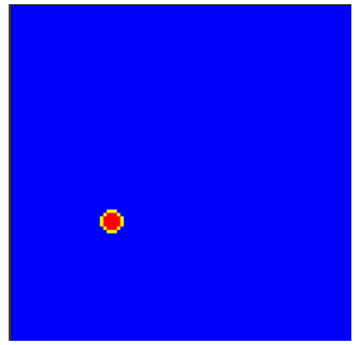
Panel (b) Insertion of 15 peacekeepers into the lump (period 3)



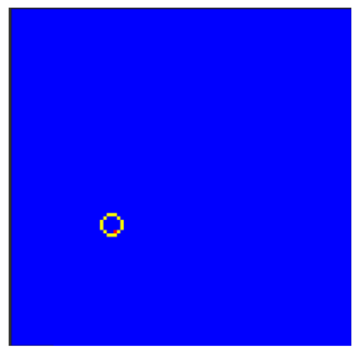
Panel (c): Peacekeepers too little too late. Lump seriously metastasizing (period 15)



Panel (d): Similar period 3 lump of aggressive types (period 3)



Panel (e): Insertion of 20 peacekeepers into the lump (period 3)



Panel (f): Aggressive lump is contained (period 4)

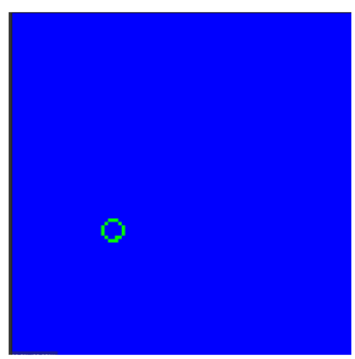
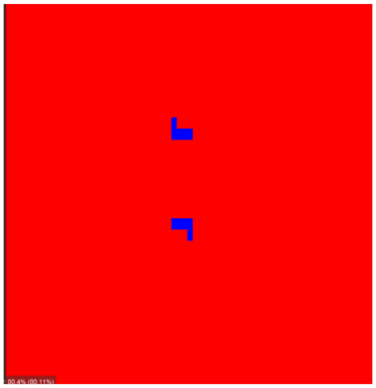
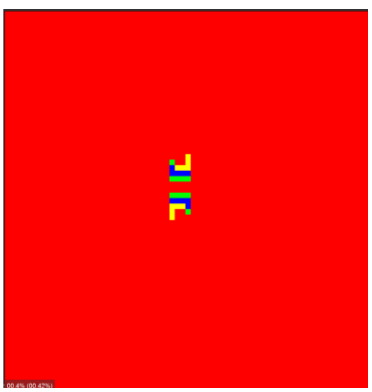


Figure 9: "Walkers" and the "Big Bang" of Peace in the Moore Village (*a*=0, *b*=1.51, *c*=0, *d*=1, $r_A^0 = 0.996$, *N*=4,761, Player updates: best wins equal stay, Population updates: synchronous)

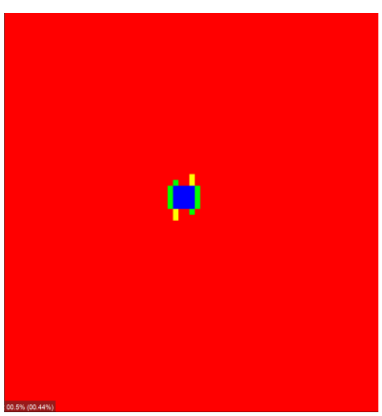
Panel (a): 2 walker teams of 10 peaceful types inserted at time 0



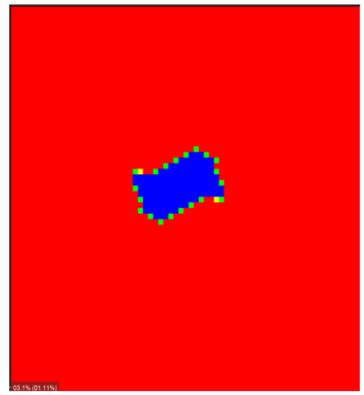
Panel (b): By time 6, the walker teams are close to concentrating



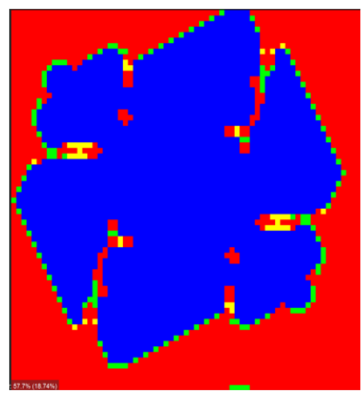
Panel (c): At time 8, the walkers connect and the "big bang" of peace begins



Panel (d): By time 15, the big bang of peace continues to grow



Panel (e): By time 60, peace is dominant



Panel (f): By time 150, village is mostly peaceful with locales of aggressive types

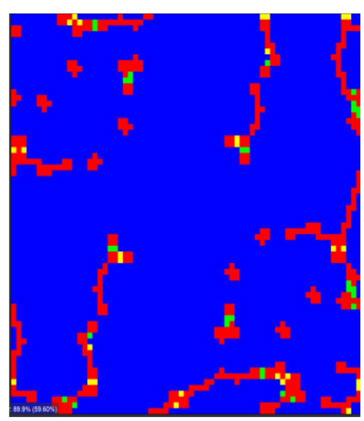
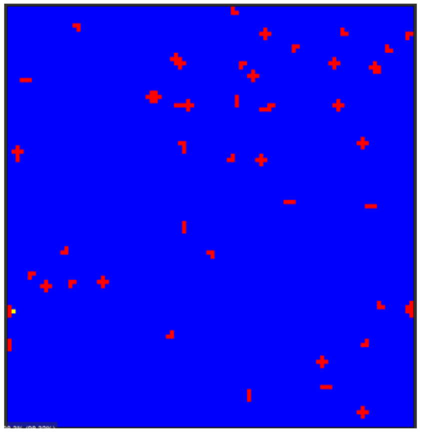
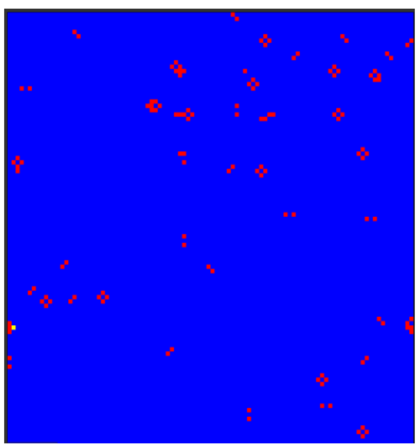


Figure 10: Peacekeeping and the Fate of the von Neumann Village (*a*=2.7, *b*=1, c=*1*, d=*2*, $r_A^0 = 0.10$, *N*=10,000, Player updates: best wins equal stay, Population updates: synchronous)

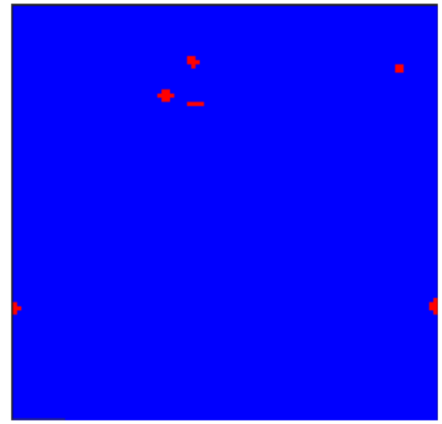
Panel (a): Blocks of aggressive types emerge by period 3



Panel (b): Insertion of 1 peacekeeper into each aggressive block (period 3)



Panel (c): By time 10, only blocks that had 6 or more aggressive types at time 3 persist



Panel (d): Insertion of 1 peacekeeper into aggressive blocks of 5 or fewer and 2 peacekeepers into aggressive blocks of 6 or more (period 3)

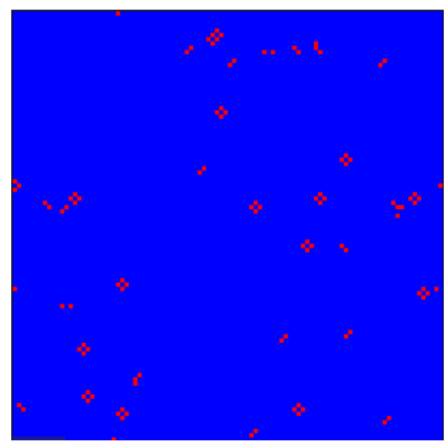
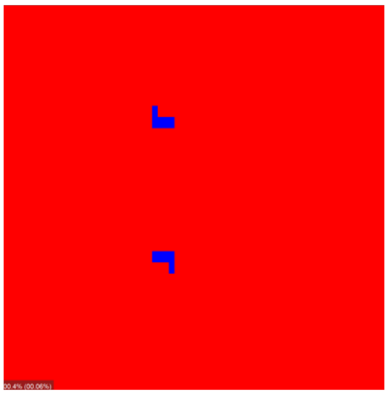
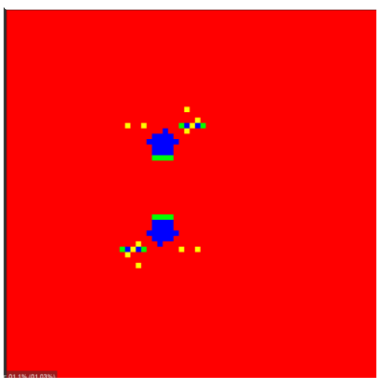


Figure 11: "Walkers" and the "Small Band" of Peace in the von Neumann Village (*a*=0, *b*=1.51, *c*=0, *d*=1,$r_A^0 = 0.996$, *N*=4,761, Player updates: best wins equal stay, Population updates: synchronous)

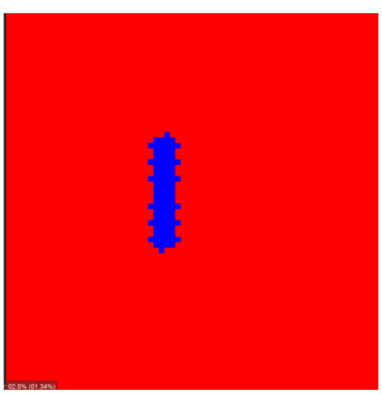
Panel (a): 2 walker teams of 10 peaceful types inserted at time 0



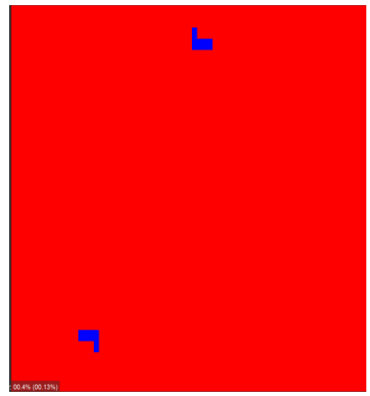
Panel (b): By time 6, the walker teams are close to concentrating



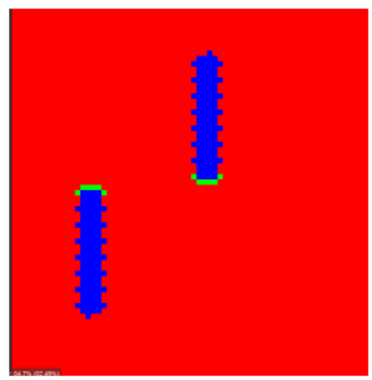
Panel (c): At time 12, the walkers connect but a "big bang" of peace does not occur



Panel (d): 2 non-overlapping walker teams of 10 peaceful types inserted at time 0



Panel (e): By time 25, each walker team is carving out "small band" of peace



Panel (f): By time 75, the "small bands" of peace have spread as far as they can

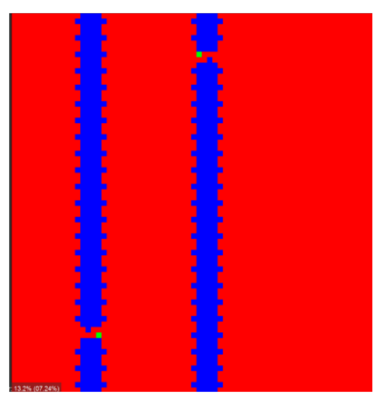


Table 1: Four Possible Cases of the Social Evolution of Aggression

1. **Case 1: $a<c$ and $b<d$ ➔ Peace dominates**
   - Parameters imply aggressiveness unrewarded relative to peacefulness in social encounters

2. **Case 2: $a<c$ and $b>d$ ➔ Peace and Aggression coexist**
   - Parameters imply aggressors relatively well rewarded in social encounters with peaceful types

3. **Case 3: $a>c$ and $b<d$ ➔ Peace and Aggression bistable**
   - Parameters imply aggressors relatively well rewarded in social encounters with other aggressors

4. **Case 4: $a>c$ and $b>d$ ➔ Aggression dominates**
   - Parameters imply aggressiveness rewarded relative to peacefulness in social encounters

Table 2: Manipulating the Social Genome: Selected Nazi Techniques that Foster the Social Evolution of Aggression in the 2x2 Evolutionary Game Model

1. Increase payoffs to aggressive phenotypes in same encounters (increase *a*)
    a. Mass changes in law that favor the occupiers and disfavor the occupied (p. 25)
    b. Support of Germanism rewarded in economic life (pp. 195, 206, 224)

2. Increase payoffs to aggressive phenotypes in cross encounters (increase *b*)
    a. Mass changes in law that favor the occupiers and disfavor the occupied (p. 25)
    b. Appropriation of property from occupied groups (pp. 37-40, 144)
    c. Legal rights of occupied replaced by "grace" of occupant (p. 71)
    d. Support of Germanism rewarded in economic life (pp. 195, 206, 224)

3. Decrease payoffs to peaceful phenotypes in cross encounters (decrease *c*)
    a. Mass changes in law that favor the occupiers and disfavor the occupied (p. 25)
    b. Appropriation of property from occupied groups (pp. 37-40)
    c. Refuse unemployment relief for those unwilling to work for Germany (p. 69)
    d. Legal rights of occupied replaced by "grace" of occupant (p. 71)
    e. Severe penalties to those who help victim groups (p. 77)
    f. Resistance to Germanism penalized in economic life (pp. 195, 206, 224)

4. Decrease payoffs to peaceful phenotypes in same encounters (decrease *d*)
    a. Mass changes in law that favor the occupiers and disfavor the occupied (p. 25)
    b. Disrupt centers of political resistance (p. 67)
    c. Separate families (p. 67)
    d. Exclude people from liberal arts education (pp. 84, 229)
    e. Undermine religious affiliations and leadership in occupied territories(p. 89)
    f. Create an atmosphere of moral debasement (pp. 89-90)
    g. Appropriation of the gains from trade within occupied territories (pp. 127, 229)
    h. Imprisonment or liquidation of key leaders (p. 139)
    i. Resistance to Germanism penalized in economic life (pp. 195, 206, 224)
    j. Assembly restricted (p. 231)

5. Increase initial ratio of aggressive phenotype in locales (increase r_A^0)
    a. Ideological penetration and fifth column support of Nazism (pp. 19, 83, 137, 237)
    b. Mass deportations of native populations (pp. 21, 67)
    c. Subsidies and tax breaks for German settlers in occupied territories (pp. 21, 63, 225)
    d. Insertion of "colonization staffs" into occupied territories (p. 21)
    e. Currency manipulation to finance insertion of aggressive types into areas (pp. 51-53)

Notes
1. The parameters *a*, *b*, *c*, *d*, and r_A^0 are the parameters of the stage game for the basic model in Figure 1.
2. The page numbers in the table refer to pages in Raphael Lemkin's (1944) *Axis Rule in Occupied Europe*.