

**Cultural change in spatial environments:
the role of cultural assimilation and of internal changes in cultures**

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Abstract

A cellular automata model is used to study some aspects of cultural change in spatial environments. Cultures are represented as bit strings contained in the individual cells of a grid of cells. The culture of a cell may change because (a) it tends to become more similar to prevailing neighboring cultures, (b) it is subject to intrinsic random changes, and (c) it occupies previously empty neighboring cells. Extending the results of Axelrod (1997), we show that assimilation does not lead to a single homogeneous culture but stable cultural boundaries separate different cultural regions, intrinsic changes reduce rather than increasing the number of stable cultural regions, and even expansion of a single culture in a previously unoccupied territory does not result in a single culture in the entire territory. Geographical features (such as mountains) that are an obstacle to assimilation between close cells increase the number of different cultural regions in a territory. We discuss the results with reference to the problem of "ethnicity" and with regard to simulations published elsewhere in which the model is used to study the agricultural colonization of Europe from the VII to the IV millennium B.P.E.

Introduction

Culture is behaviors, languages, beliefs, attitudes, and values which individuals learn from other individuals (Cavalli-Sforza and Feldmann 1981; Boyd and Richerson 1985). Every human group has its own distinctive culture but the cultures of human groups which are in reciprocal contact tend to become more similar because individuals in one group may learn some of their behaviors, language, beliefs, attitudes, and values from individuals in other groups with which they interact. One would then predict that, if a territory contains several human groups each with its own distinctive culture but neighboring groups interact, given enough time there will be only a single homogeneous culture in the entire territory. Using a simple simulation model, Axelrod (1997) has shown that this is not so. Starting from an initial condition in which the cultures of the human groups existing in a territory are randomly generated and therefore tend to be different, there is in fact a process of progressive cultural homogenization, with neighboring groups converging on a

common culture, but this process never reaches completion. The simulation ends up in a steady state in which a small number of different cultures continue to exist and have no tendency to further coalesce into a single, unified, culture.

Axelrod's simulations are based on the assumption that the tendency of two neighboring human groups to influence each other and to become more culturally similar depends on their current level of cultural similarity. Two groups which are already culturally similar are more likely to interact and therefore to become even more culturally similar. On the contrary, two neighboring groups with zero cultural similarity are unlikely to interact and therefore they will have no tendency to become more culturally similar. One might think that it is this assumption of Axelrod's model that explains why his simulations never end up with a single homogeneous culture. If two neighboring groups have completely different cultures and have no tendency to change their cultures because they are already part of culturally homogeneous regions, the two groups will for ever keep their different cultures and there will never be complete cultural homogeneization.

In this paper we show that Axelrod's result of no complete cultural homogeneization obtains even if we abandon his assumption that neighboring groups with completely different cultures cannot influence each other. We describe some simulations in which no single unified culture eventually emerges even if neighboring groups with completely different cultures can interact and influence each other, and therefore become more culturally similar. Furthermore, we show that this is the case even if we add a new factor, internal (random) changes in the cultures of human groups, which is absent in Axelrod's simulations (but mentioned in his paper; cf. Axelrod 1997). Internal changes in cultures should favour cultural assimilation. One could explain Axelrod's results as due to the fact that the simulation reaches a "frozen" state in which no further change is possible because the culture of every human group is either completely identical or completely different from the culture of neighboring groups. Given the assumptions of Axelrod's model, in these circumstances there can be no further social influence and cultural assimilation. If we add random mutations which constantly take place within the culture of every group, we can rule out this explanation because these random mutations constantly "de-freeze" the situation. However, we show in our simulations that even with random mutations constantly taking place in cultures, there is no tendency for a single homogeneous culture to emerge.

In our simulations we further extend Axelrod's results by simulating a process of expansion of a single human group in an empty territory and looking at what happens to this group's original culture when during the expansion process both cultural assimilation between neighboring sub-groups and random internal changes in the culture of each sub-group take place. How the terminal picture of cultural distribution in this situation compares with that of our previous simulations in which the territory is initially already completely inhabited by human groups with different cultures? Finally, we introduce some environmental features in the territory. such as mountains, which may inhibit contact between neighboring groups and look at the process of cultural dissemination in these more realistic circumstances.

Simulation 1: Cultural assimilation

The territory is a square of $20 \times 20 = 400$ cells called sites. Each site has 8 neighboring sites (neighbors) except the sites along the sides of the square which have only 5 neighbors and those at the four corners which have only 3 neighbors. At the beginning of the simulation every site is assigned a randomly generated string of 6 bits which represents the culture of the people living in the site. If two or more neighboring sites have the same bit string, they have the same culture and belong to the same cultural region. If we count the total number of cultural regions as defined by this criterion, we find

that at the beginning of the simulation there are around 17 cultural regions, independently from the initial random assignment of the bit strings. (All the results given in the paper are based on 10 different runs of each simulation.) The general formula is $N*(N/3)*(8/N)*(1/L)$, where N is the number of sites and L is the number of possible cultures, which for a string of 6 bits is 64. (In Axelrod's model a culture is represented as a string of 5 numbers varying from 1 to 10. We adopt Epstein and Axtell's suggestion to use string of bits. Axelrod suggests that this solution would yield no more than two different cultures in its stable regions. As we will see, this is not the case in our model.)

In the first simulation the culture of each site changes only because it is influenced by the culture of neighboring sites and it becomes more similar to existing neighboring cultures. The system is updated in a succession of cycles. In each cycle the bit string of each site is modified using the following rule:

Assimilation Rule: For each bit determine which is the more frequent value (1 or 0) in the neighborhood of the site (which for internal sites includes 9 cells: the individual cell plus its 8 neighbors) and, if this value is different from the site's current value, change the current value.

This first rule is meant to capture the fact that if some people (those living in a site) are in direct contact with other people (those living in the neighboring sites) the properties of their culture will become more similar to the more frequent corresponding properties of the cultures around them (cf. Boyd and Richerson's frequency bias; Boyd and Richerson, 1985). In Axelrod's model cultural assimilation takes place because in each cycle each site randomly selects one of its neighbors and adopts one of the properties of this neighbor's culture with a probability which depends on the degree of similarity already existing between the two cultures. In our model not only assimilation is with the dominating culture of a site's entire neighborhood but, most importantly, there is no role of pre-existing cultural similarity as a determinant of cultural assimilation.

We have run four sets of simulations using this scenario. In each simulation the bit strings of the sites are updated for a total of 1,000 cycles. Each simulation has been replicated 10 times starting from different initial conditions (random assignment of the bit string to the individual sites). The results of the simulations are described using three measures:

1. Local uniformity: average number of bits in the culture of a site which have the same value of the corresponding bit of neighbors.
2. Number of cultural regions: total number of cultural regions where a cultural region is defined as two or more neighboring sites with exactly the same culture (bit string). There may be cultural regions which are constituted by the same bit string but which count as different regions because they are spatially separated.
3. Number of isolates: total number of sites which do not belong to any cultural region, i.e., which have no neighbors with the same bit string.

Figure 1-3 show how the value of the three variables, local uniformity, number of cultural regions, and number of isolates, changes across the 1,000 cycles of Simulation 1. After only 10-20 cycles all the three variables reach a steady state. All the figures give average and standard deviation for 10 replications of the simulation.

Local uniformity, which can be taken as a general measure of cultural uniformity, starts at a value of about 3 and reaches a stable value of slightly less than 5.4 (maximum value is 6: all sites have identical bit strings) (Figure 1). The number of cultural regions is around 17 at the beginning of the simulation and it reaches a value of about 37 at steady state (Figure 2). At the beginning of the simulation most sites are cultural isolates and for purely random reasons only in 17 cases it happens that two (or perhaps three) neighboring sites have the same culture. After the Assimilation Rule has operated, there is a significant increase in the number of geographical regions which share the same culture (and of course also in their size). The number of isolates is 355 at the beginning of the simulation and only 13 at the end. This means that there is a strong increase in the number of sites that share the same culture of neighboring sites and become part of cultural regions (Figure 3).

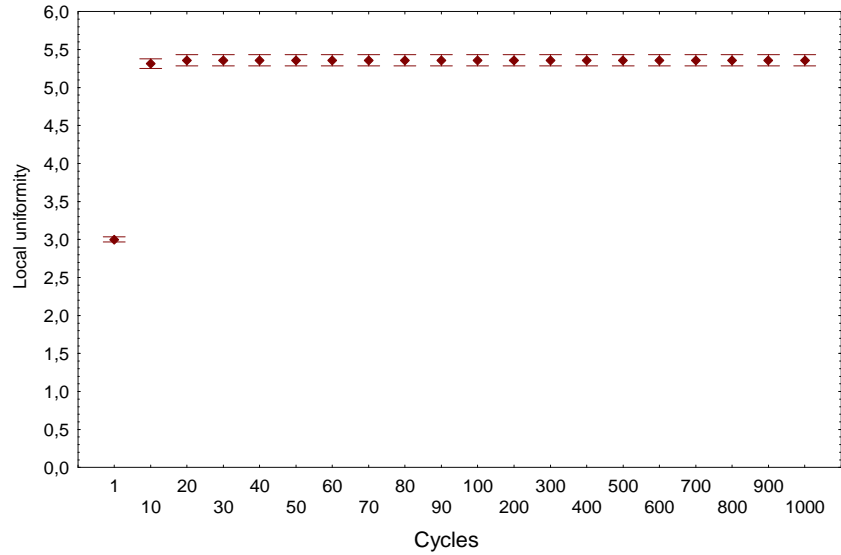


Figure 1. Local uniformity (average number of bits in each sites which have the same value of the corresponding bit of neighboring sites) across 1000 cycles.

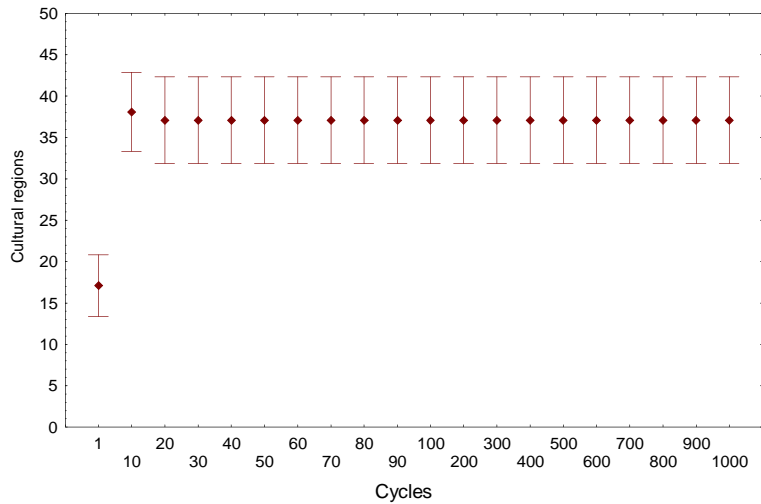


Figure 2. Total number of cultural regions (neighboring sites with the same bit string) across 1000 cycles.

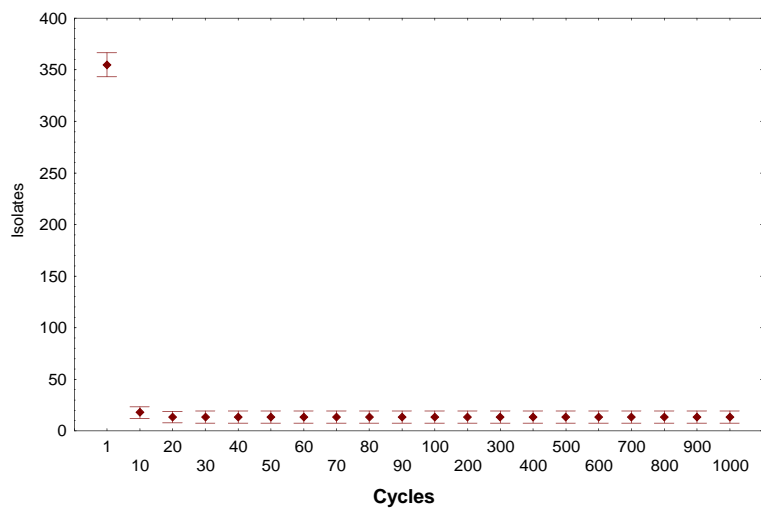


Figure 3. Total number of isolates (sites which do not belong to a cultural region) across 1000 cycles.

The results of this first simulation tell us that, not unexpectedly, if we apply the Assimilation Rule there is a tendency toward greater cultural uniformity. Neighboring cells assimilate each other and this leads to more local uniformity (a site is more likely to be culturally similar to a neighboring cell at the end of the simulation than at the beginning of the simulation), to a greater number of cultural regions, i.e., groups of neighboring sites which have the same culture, and to a sharply decreased number of isolates, i.e., sites which have a culture not shared by any of their neighboring sites. The interesting result is that even if we apply the Assimilation Rule repeatedly (for 1,000 cycles) the system reaches a stable state in which there is not complete cultural uniformity, i.e., a single culture. In other words, we obtain the same result of Axelrod's simulation but this result cannot be attributed to a tendency to interact with and be culturally influenced by only neighbors with which there already exists some degree of cultural similarity. In Axelrod's simulation if two neighboring sites have completely different cultures, they cannot interact and influence each other. Hence, there is no further room for cultural assimilation and the system become "frozen" with a (small) number of cultural regions. In our simulation interaction and social influence take place with all neighbors whatever the degree of cultural similarity and still the system does not end up with a single homogenous culture.

Why in Simulation 1 the Assimilation Rule does not lead to total uniformity but only to a somewhat restricted number of cultural regions? The reason appears to be the following. The application of the Assimilation Rule in the early stages of the simulation causes the emergence of limited regions sharing the same culture and originating in a number of spatially separated locations. However, since their spatial point of origin varies, these regions of local cultural uniformity tend to have different bit strings, that is, to have different cultures. When the process of local uniformation expands and these different cultural regions come into contact, it is too late for two different cultural regions to fuse together. Two neighboring sites with different cultures will keep their different cultures - the Assimilation Rule notwithstanding - because the pressure to change due to the single neighboring site which has a different culture tends to be overwhelmed by the conservative pressure exerted by the other, more numerous, neighboring sites which share the same culture of the particular site. In other words, being part of a cultural region decreases a site's chances to change its culture and be influenced by a neighboring site not belonging to the same cultural region. Therefore, the process of cultural uniformation stops and boundaries separating different cultural regions emerge and become stable.

Simulation 2: Internal changes in cultures

Cultures can change because of external influences but also for internal reasons. We try to capture the internal changes that take place in cultures by adding a second rule to the functioning of our system:

Mutation Rule: In each cycle change the value of each bit of the bit string of each sites with a given probability (mutation rate).

In Simulation 2 we apply both the Assimilation Rule and the Mutation Rule, in this order, to all sites. Furthermore, in separate sets of simulations (10 replications for each set) we use four different mutation rates: .01%, 1%, 10%, and 20%. A mutation rate of, for example, 1% means that a particular bit of a particular bit string has 1% probability to change its value from 1 to 0 or from 0 to 1.

As in Simulation 1, the three variables (local uniformity, number of cultural regions, number of isolates) reach a stable value after only 10 to 20 cycles. Figure 4-6 show the values of the three variables for each of the 4 mutation rates at the end of the simulation, plus their values for the condition with no mutation rate (Simulation 1) for comparison purposes.

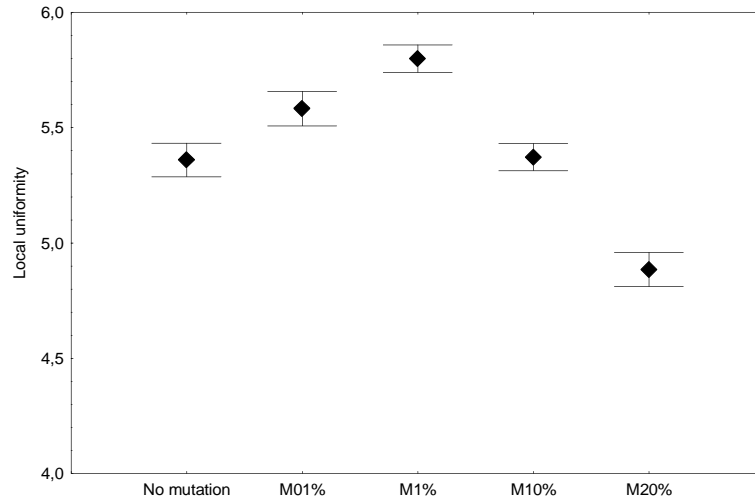


Figure 4. Local uniformity at the end of the simulation for zero mutation rate (Simulation 1; cf. Figure 1) and for mutation rates of .01%, 1%, 10%, and 20%.

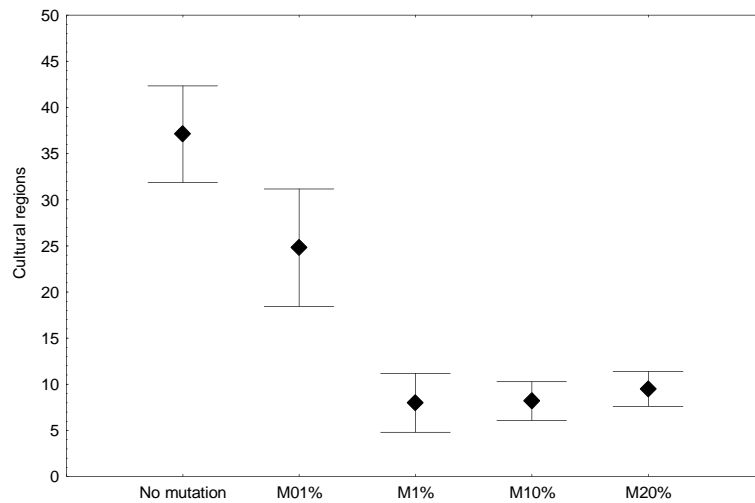


Figure 5. Total number of cultural regions at the end of the simulation for the same mutation rates of Figure 4.

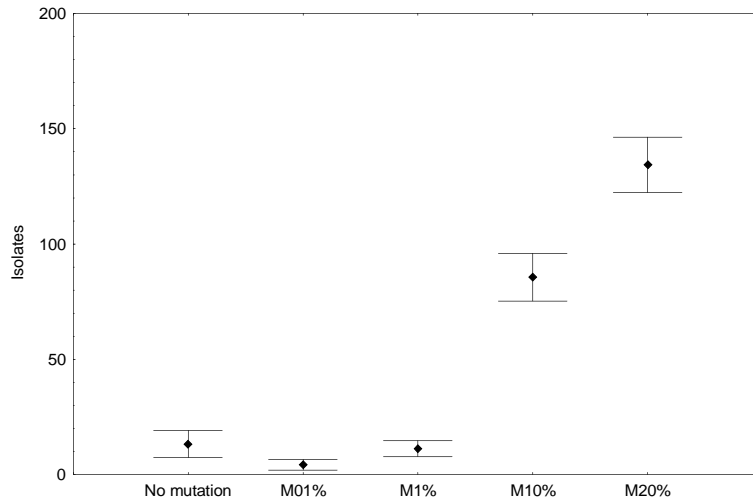


Figure 6. Total number of isolates at the end of the simulation for the same mutation rates of Figure 4.

The interesting result of Simulation 2 is that, somewhat counterintuitively, the number of cultural regions decreases with increasing mutation rates. With 0% mutation rate, as we have seen, there is an average of 37 cultural regions at stable state. With a mutation rate of .01% the cultural regions are reduced to 24 and with a mutation rate of 1% there are only 8 cultural regions. Only with further increases in mutation rate (10% and 20%) there is a slight increase in number of cultural regions (9 and 10, respectively). One would have thought that mutations, by increasing the overall variability of cultures, would cause the existence of a greater number of different cultural regions. It is not so. Cultural change due to internal mutations tends to decrease the number of existing cultural regions.

The effect appears also when we examine the other two variables, local uniformity and number of isolates. Local uniformity increases from a value of less than 5.4 when there are no mutations (Simulation 1) to a value of slightly less than 5.6 with .01 mutation rate and a value of slightly less than 5.8 with 1% mutation rate. As with the number of cultural regions, only still higher mutation rates cause a reduction of local uniformity, which is about 5.4 for 10% mutation rate and about 4.9 for 20% mutation rate. The number of isolates reaches a value of almost zero with .01% mutation rate and it gradually increases with increasing mutation rates.

In Simulation 2 we apply both the Assimilation Rule and the Mutation Rule. The effect of the Mutation Rule is to increase the overall variability of the system and therefore this rule should go against the Assimilation Rule which tends to increase the system's uniformity. The results show that the situation is more complex. As we have seen, instead of increasing the overall variability of the system the Mutation Rule, at least for low values of the mutation rate, leads to an increase of its uniformity: greater local uniformity, fewer cultural regions, fewer isolates. This appears to be due to the fact that cultural mutations tend to increase the internal variability of cultural regions and this leads to less rigid boundaries between different cultural regions. As we have seen, after an initial phase of local uniformation leading to a decreased number of cultural regions and a strong reduction in the number of isolates, when different cultural regions come into contact the internal homogeneity of cultural regions is an obstacle to further uniformation. Two neighboring sites possessing different cultures will tend to retain their different cultures because the internal homogeneity of the cultural regions to which the two sites belong tends to be an insurmountable obstacle to reciprocal assimilation. It is quite

impossible for a site to change its culture by coming into contact with another culture if the other sites with the same culture of the site all uniformly push the site in the same conservative direction.

The addition of the Mutation Rule changes this situation. The Mutation Rule reduces the internal homogeneity of cultural regions and therefore makes it more probable that a site with a given culture may change its culture when it comes into contact with another culture since there will be less uniform conservative pressure from the other sites possessing the same culture of the site. In general terms, the effect of the Mutation Rule is to keep the entire system in a constant flux of change. This, perhaps paradoxically, leads to greater cultural uniformity rather than to less uniformity. By increasing the internal variability of cultural regions the Mutation Rule makes the boundaries between different cultural regions less rigid and easier to pass and this may lead to further extension of the process of cultural unification.

Simulation 3: Cultural expansion

In Simulations 1 and 2 all the sites already possess a culture when the simulation begins and what we observe in the course of the simulation is how the culture possessed by each site changes as a function of various factors. Now imagine a situation in which at the beginning of the simulation all the sites are culturally empty, that is, no culture exists in the sites, except for a single site which already possesses a culture (a particular bit string). The dynamic of the system includes a third rule:

Expansion Rule: For each site, if the site already possesses a culture and one or more neighbors of the site are culturally empty, copy the culture possessed by the site in one randomly chosen empty neighbor.

In other words, we assume that at the beginning of the simulation only one site in the entire territory has a culture but the culture possessed by this single site expands to neighboring sites if these sites do not already have a culture until all the sites in the territory have some culture (the initial condition in Simulations 1 and 2). At the same time the other two rules, the Assimilation Rule and the Mutation Rule, are applied both during the expansion process (which terminates when all the sites possess some culture) and after. Simulation 3 applies the three rules in this order: Assimilation Rule, Expansion Rule, Mutation Rule.

We have run 10 replications of Simulation 3 by randomly varying the position in the territory of the single site already possessing a culture at the beginning of the simulation. It takes a relatively small number of cycles to complete the cultural expansion process (around 50 cycles) but the simulation lasts until the end (1,000 cycles). The most important result of Simulation 3 that if we add cultural expansion the number of cultural regions at steady state is smaller than in Simulations 1 and 2. As Figure 7 shows, with a mutation rate of 1%, which yields the smallest number of cultural

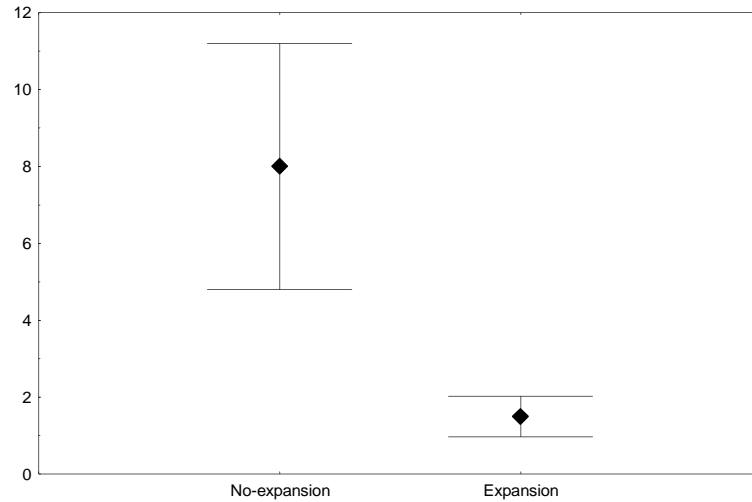


Figure 7. Total number of different cultural regions at the end of the simulation when all sites already contain some culture at the beginning of the simulation (Simulation 2) (No-expansion) and when only one site contains a culture at the beginning of the simulation and then this culture expands to other sites (Expansion).

regions (cf. Figure 4), the number of cultural regions is 8 if we start with an environment already filled with culture (Simulation 2) but is only 2 if we include cultural expansion, i.e., if we start with only one site possessing a culture which is allowed to expand in an initially culturally empty environment.

This result is not very surprising since when the expansion process is terminated all sites have a culture which is derived from the same initial culture. This simulation appears to be more realistic since in many historical cases the different cultures existing in different portions of a given territory are derived from a single localized culture which has expanded to the entire territory. What may be of some interest is that, given the Assimilation Rule which tends to homogenize neighboring cultures, an internal cultural mutation rate of 1% is unable to push the number of emerging different cultural regions beyond 2 whereas the same cultural mutation rate results in 8 different cultural regions if all the sites initially have randomly generated cultures, as in Simulation 2. It remains to be seen what would happen if we increase the internal mutation rate of cultures. As we saw, increasing the mutation rate to 10% or 20% only slightly increases the number of cultural regions in Simulation 2 (cf. Figure 4). Would an analogous increase in mutation rate lead to a much larger number of cultural zones when all cultures are derived from a single initial culture through expansion? This would make the role of internal cultural changes very different in the two cases. As we know, internal cultural changes erode the rigidity of cultural boundaries and lead to more cultural homogenization and fewer cultural zones when the starting condition is one of extreme cultural heterogeneity. On the contrary, in a situation in which all local cultures are derived from a single initial cultures increasing the rate of internal cultural changes might lead to more cultural heterogeneity and more cultural regions.

The existence of a preceding historical process of cultural expansion from a single initial site has another consequence of interest. We can observe this consequence if we compare what happens in Simulation 3 after the cultural expansion process is completed and all the sites contain a culture, that is, from around cycle 50 to cycle 1,000, with the results of Simulation 2 in which the simulation starts with all the sites already containing a culture. In Simulation 3 the number of cultural regions at the end of the expansion period, i.e., at cycle 50, is 5.5 on the average with a large inter-seed variance of 2 to 12. At this point the situation can be compared to that of our Simulation 2 in which the simulation starts with an already culturally filled territory. To make the comparison possible we have run another simulation in which at the

beginning of the simulation, like in Simulation 2, all the sites of the territory have a culture, the culture is randomly generated and is not the result of an expansion process, but we have manipulated the simulation so that the number of cultural regions at the beginning of the simulation is 5.5 with the same variance. At the end of the new simulation, after 1,000 cycles, the number of cultural regions is 3, whereas in Simulation 3 the number of cultural regions was only 1,5 (Figure 7a). The difference is small but statistically reliable. This means that a preceding process of cultural expansion from a single initial site leaves a trace in the further cultural dynamics which takes place in the territory after the process of cultural expansion has been completed and all the sites have a culture.

Simulation 4: Artificial geographies

In all the simulations described so far the territory is geographically homogeneous. It contains no geographical features (mountains, rivers, etc.) which may constitute an obstacle to cultural expansion and assimilation. In a final simulation, Simulation 4, cultural expansion and assimilation take place in a territory which is not geographically homogeneous but includes a very abstract and very simple geography which may influence the cultural dynamics taking place in the territory. The territory includes a series of parallel mountain ranges (filled cells in Figure 8) which make it impossible for a site to culturally expand to and/or influence a neighboring site which lies on the other side of the range. In this geographical environment we have run the same simulation of Simulation 2: at the beginning of the simulation all sites already contain a randomly generated culture and then the Assimilation Rule and the Mutation Rule control how cultures change.

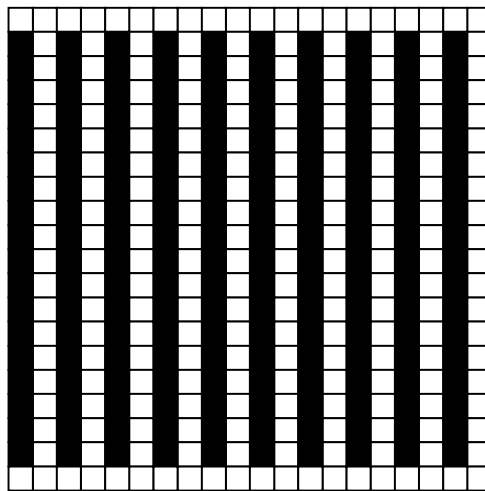


Figure 8. An environment with an artificial geography. Black cells are mountains.

The result of Simulation 4 is that geography leads to a considerable increase in the number of cultural regions. With no geography the number of cultural regions at the end of the simulation is 8 (Simulation 2), whereas with mountains (or other similar natural features) which are an obstacle to contact and social influence the terminal number of cultural regions is 30.

Discussion

If local cultures tend to influence each other and to become more similar to neighboring cultures there should be a tendency towards complete cultural homogeneity. If we start with a set of different local cultures in the end there will only be a single unified culture. That this is not true can be shown with simple simulations in which a territory is divided into a set of local sites, each with its own particular culture, there is a tendency of local cultures to change and become more similar to nearby cultures so that homogeneous cultural regions emerge which include many neighboring sites, but then the situation reaches a stable state in which there is a small number of different cultural regions which appear not to have any tendency to fuse into a single culture.

What causes the persistence of different cultural regions even if neighboring cultures tend to assimilate reciprocally? In his simulations Axelrod (Axelrod 1997) hypothesizes that two neighboring sites will culturally assimilate reciprocally with a probability which depends on the current degree of cultural similarity. This implies that neighboring cultures with zero cultural similarity will have no tendency to change and become more similar one to the other. Hence, when two neighboring cultures which are part of two different internally homogeneous cultural regions are in contact and the two cultures have zero cultural similarity, the situation becomes frozen, there is no further cultural change, and the two cultural regions will never fuse into a single, greater, cultural region. In the simulations described in the present paper we adopt Boyd and Richerson's "frequency bias" hypothesis as a mechanism for cultural change to obtain similar results (Boyd and Richerson 1985). The frequency bias is the idea that an individual or a group will have a tendency to adopt the cultural traits that are more frequently exhibited in its social environment. In our model a site will change some aspect of its culture if it is different from the corresponding aspect of the majority of the cultures of its neighboring sites and it will adopt the majority's aspect. On the other hand, unlike Axelrod's simulations, in our simulations cultural assimilation can take place even among sites with zero degree of cultural similarity. We find that in even in the new scenario cultural assimilation does not lead to complete cultural homogeneity. The reason is that when two culturally different neighboring sites belong to two different internally homogeneous cultural regions the pressure not to change emanating from the cultural region each site belongs to tends to be greater than the pressure to change due to contact with the different culture of the neighboring site. Hence, each of the two sites will stick to the culture of its cultural region and there will be no further cultural homogenization and no emergence of a single unified culture. This result, together with the results of Axelrod's simulations, shows that the tendency to preserve a certain degree of cultural heterogeneity is a robust phenomenon which can be due to a variety of causes and which manifests itself in a variety of conditions.

In our simulations we have explored the role of additional factors in the cultural dynamics of a given territory. We have assumed that, beyond cultural change due to contact with other cultures, cultures may change for internal reasons (selective reproduction of cultural traits, invention of new traits, random "errors" in cultural transmission, etc.). We capture these internal changes of cultures by randomly changing some of their components in each cycle with a given probability (mutation rate). What are the consequences of these internal changes for the global cultural dynamics of a territory? Although one might have the tendency to think that internal changes will lead to greater cultural variability and therefore to an increase in the eventual number of different cultural regions, the results of our simulations indicate that just the opposite is the case. When we compare simulations with cultural assimilation but no internal changes in cultures with simulations with both cultural assimilation between neighboring sites and internal changes in the culture of

each site, we find that the terminal number of cultural regions is smaller in the latter case than in the former. The reason appears to be that internal random changes tend to reduce the rigidity of the cultural boundaries between different cultural regions. They produce less internal homogeneity in cultural regions which may reduce the pressure not to change for sites located near the boundary with other cultural regions. In this way, even when two bordering cultural regions have already emerged there still is the possibility that one of the two regions will progressively “eat” the other region until they become a single unified cultural region. This will tend to reduce the number of different cultural regions when the system reaches a stable state. However, as a testimony to the strength of the factors that prevent complete homogenization, even in these circumstances there will more than a single cultural region at the end of the simulation.

In another set of simulations we have explored another variable that may have a role in determining the cultural composition of a given territory. The different cultures that we observe in a given territory in many historical cases are the result of a process of diffusion of a single culture (with either demic or cultural diffusion) initially restricted to a small proportion of the entire territory. In these new simulations all the sites of the territory are culturally empty at the beginning of the simulation except a single site. The culture of this site is copied in neighboring empty sites until all the sites are filled with culture. At the same time both processes of cultural change, i.e., cultural assimilation among neighboring sites based on the “frequency bias” and internal random changes, take place as the territory is gradually filled with culture and for a certain number of cycles subsequently. The result is that the number of different cultural regions when the system reaches a stable state is smaller than in the two preceding simulations. The common origin from a single culture reduces the cultural variability which is created by the internal random changes constantly taking place in each site possessing a culture. This common origin and the cultural assimilation among neighboring sites result in fewer cultural regions than in the simulations in which only cultural assimilation is at work and the initial state is one of more or less complete cultural heterogeneity. The common origin appears to leave a permanent trace in the cultural composition of the territory. In fact, even after the cultural diffusion process has been completed and then the simulation goes on for a large number of additional cycles, the terminal number of cultural regions turns out to be smaller in the simulations in which this filled state results from a preceding phase of cultural diffusion than in the simulations in which the initial filled state is randomly generated, although we manipulate the conditions of the latter simulation so that the number of cultural regions is initially the same in both conditions. Clearly, descending from a single common culture creates a condition of underlying cultural similarity which is still visible long after factors of cultural differentiation (internal changes) and local assimilation have operated.

The simulation scenario of Simulation 3 appears to be more realistic than that of the first two simulations in that it is historically often the case that the different cultures existing in a given territory all descend from a single culture initially restricted to a certain portion of the territory and then diffusing to the entire territory. Another factor influencing the cultural dynamics in real territories is the geographical structure of the territory, which may include features preventing or favoring cultural contact such as mountains and rivers. In our last simulation we have made an initial exploration of the role of this factor in the cultural dynamics of a territory by introducing a simple system of mountains in the territory that constitute an obstacle to cultural contact and therefore cultural assimilation. As expected, this results in a larger number of cultural regions at the end of the simulation.

This of course is just scratching the surface of the problem of the role of real geographies in territorial cultural dynamics. More recently, we have realized a different set of simulations (Antinucci, Cecconi, Natale, and Parisi 2002) in which we use a realistic geographical map of Europe and of portions of the Middle East to study how agriculture diffused from Anatolia to the whole of Europe in 3-4 thousand years beginning from the VII millennium B.P.E. (Before Present Era). (Ammerman and Cavalli-Sforza 1984). The purpose of these simulations is to study the role of geographical factors in the diffusion process, the different paths of diffusion followed by different groups of people (assuming this was a prevalently demic diffusion), and the resulting genealogical tree connecting different cultures in different places (or different languages, if the simulation can be used to test Colin Renfrew's hypothesis about the Anatolian origin in the VII millennium of the Indoeuropean languages (Renfrew 1987)).

The abstract simulations reported in this paper and the historical/geographical simulations described in Antinucci, Cecconi, Natale, and Parisi (2002) can be discussed together to formulate an hypothesis about the role of "ethnicity" as a condition leading to the creation of larger and more complex socio-political units (chiefdoms, cities, states) in Europe in the last millennia B.P.E. In our model cells can be similar either because they share inherited traits (inherited similarity; cf. our model of cultural expansion) or because they have become more similar due to interaction based on spatial proximity (acquired similarity; cf. our Assimilation Rule). Ethnicity can be defined as genetic/cultural/linguistic similarity due to shared inheritance in an environment in which all the cells have a culture which results from a process of cultural expansion from a single initial cell (culture). In other words, ethnicity is inherited similarity, not acquired similarity. Cells that are similar because of inherited similarity, i.e. because they have the same ancestors, tend to be less and less similar with increasing spatial/temporal distance from the point in which their ancestors have separated into different lines (spatial paths) because intrinsic cultural changes accumulate and cause cultural divergence (cf. our Mutation Rule). The model of the agricultural colonization of Europe described in Antinucci, Cecconi, Natale, and Parisi (2002) can be used to generate a ethnic map of Europe at the end of the colonization process in the IV millennium in which ethnic regions are defined either using a threshold of inherited similarity between adjacent cells (a given number of cycles since separation) or using both inherited similarity and acquired similarity as a criterion for the identification of an ethnic group. The two maps can then be compared with actual empirical (archaeological, linguistic, historical) data on the emergence of larger and more complex socio-political units in the 3-4 millenia B.P.E. in Europe to verify which of the two maps matches better with the empirical data.

References

- Ammerman, A. J. and Cavalli-Sforza, L. L. 1984. *The Neolithic Transition and the Genetics of Populations in Europe*. Princeton: Princeton University Press.
- Antinucci, F., Cecconi, F., Natale, F., and Parisi, D. 2002. *Simulating the Indo-European Expansion using a Cellular Automaton*. Institute of Cognitive Science and Technology, National Research Council, Rome.
- Axelrod, R. 1997. The dissemination of culture: a model with local convergence and global polarization. *Journal of Conflict Resolution*, 4:203-226.
- Boyd, R. and Richerson, P. J. 1985. *Culture and the Evolutionary Process*. Chicago: Chicago University Press.
- Cavalli Sforza, L. L. and Feldman, M. W. 1981. *Cultural Transmission and Evolution. A Quantitative Approach*. Princeton: Princeton University Press.
- Renfrew, C. 1987. *Archaeology and Language. The Puzzle of Indo-European Origins*. London: Jonathan Cape.