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AGENT-BASED COMPUTER SIMULATIONS OF LANGUAGE CHOICE DYNAMICS

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ABSTRACT

We use agent-based Monte Carlo simulations to address the problem of language choice dynamics in a tripartite community which is linguistically homogeneous but politically divided. We observe the process of non-local pattern formation that causes populations to self-organize into stable antagonistic groups due to the local dynamics of attraction and influence between individual computational agents. Our findings uncover some of the unique properties of opinion formation in social groups when the process is affected by asymmetric noise distribution, unstable inter-group boundaries, and different migratory behaviors. Although we focus on one particular study, the proposed stochastic dynamic models can be easily generalized and applied to investigate the evolution of other complex and nonlinear features of human collective behavior.

INTRODUCTION

When countries break up, the emergence of novel languages is usually one of the first observable outcomes, although the linguistic fragmentation often precedes the political one. In recent years, asymmetric power relations and the continuing struggle for the accumulation of linguistic capital [1], [2] have been especially evident in the Balkans – a region with a rich history of ethnic conflict – where the past war experiences still tend to shape the process of opinion formation and largely define the nature of (non)cooperative behavior among groups with various mutual affinities. Moreover, some of the states in the region are still struggling with what is often referred to as *nation building* [3], [4], with the ever-growing instability and fragmentation at various socio-political scales [5], [6], often characterized by the negation of the state regime and national identity of the "other" and accompanied by bitter linguistic crusades, the goal of which has been to establish or annihilate the existence of the "successor languages" [7].

In many areas of the Southeast Europe, language identity has become more than just an emotional and a politically driven matter. It has almost turned into a sacred-like value, often (mis)used not only for the purposes of an ethnic and national identification, but moreover, as a powerful instrument for the manipulation of attitudes and fabrication of cultural differences between the groups, which in turn additionally deepens the political instability in the region. The perception of linguistic identity as a sacred-like value within a given community in that region is a rather recent phenomenon [8], which has been observed in former communist and post-conflict areas. Due to the influences of nationalism and the constant political manipulation of language policies, many young people in the Southeast Europe are taught differences and not exposed to the similarities that emerged from centuries of language contact and peaceful coexistence. As a result, the language opinion dynamics can often better be explained on the basis of an individual's indifference classes rather than preferences among choices [9], since over the years, many were "instructed" to be aware of what they do not like, than what they would prefer more.

The present investigation is motivated by a phenomenon of language competition in a post-conflict area populated by three strong minority groups speaking one and the same language (linguistic homogeneity), but having diverse opinions about their own linguistic identity (political diversity) [10]. The name which such groups usually prefer for "their" language is the one of their supporting bordering or other states. In addition, this behavior might be amplified by an external influence, where a given supporting state may claim the other as its own language (as e.g. Croatia is often doing for Bosnian Croats or Greeks for their Macedonian minority). Such radically restructured metalinguistic beliefs and the political arrangements that cause their emergence may ultimately result in the unilateral imposition of completely new language policies, such that the problem of linguistic identity becomes a top political issue in a region which is in fact linguistically uniform but politically divided [11].

We address this problem in the context of opinion dynamics, where every individual can select one of the three alternative choices (each standing for the particular linguistic identity). Thus, we analyze the time evolution of a system of three coexisting language opinions where due to particular political and economic reasons (or other random factors) people are ready to trade off their linguistic identity for instrumental rewards. Consequentially, diverse opinions about linguistic identity may happen to be closer to each other at one point in time (the system moves towards a consensus) and more distanced at another (the system moves towards a polarized state/fragmentation).

For a computational analysis of this phenomenon, we employ extensive agent-based Monte Carlo simulations in the context of the model of Axelrod [12], [13] and a generalized voter model [14], [15] of opinion dynamics involving three simulated population subgroups of different mutual affinities. These generalized models were introduced elsewhere [8], [10]; however, here we partially review and expand the previous work with a novel emphasis on the existence or absence of migratory behaviors of simulated agents and by discussing the effects of different population sizes and different types of inter-group boundaries in several novel contexts.

The idea of using agent-based Monte Carlo simulations for the description of social systems [16], [17], including a number of different linguistic phenomena [18], is not a new one [40]; see also [41]. Agent-based computer simulations represent an effective way to analyze how rich interaction networks between individual agents lead to a complex global behavior of the whole community [19], explaining the extent to which certain behavioral mechanisms and/or particular external factors contribute to the final outcome of the observed process [20]. In the present paper, systematic computer simulations are conducted, showing that the characteristic global pattern of opinions indeed emerges when agents endowed with or externally influenced by a set of computationally implemented mechanisms start to interact with each other in the network.

MODELS OF OPINION DYNAMICS

Agent-based simulations have stimulated much recent research and debate in sociophysics [21], especially in the areas of language competition [18], [22], language death and survival [23], self-organization of social hierarchies [24], evolution of social groups [19], inter-ethnic conflicts [25], and opinion dynamics [10], [12], [13], [14], [15], [26], [27]. In studies of opinion dynamics we want to know how different opinions of interacting agents percolate within a given community over many generations, and whether this iterative process finally converges into the state of a consensus in one of the possible choices, or alternatively, into a state of polarization, where different options can stably coexist.

Different questions of opinion dynamics can be addressed by employing different computational models, such as the model of Ising [28], Krause and Hegselmann [29], Deffuant et al. [30], Sznajd [26], or Axelrod [12]. Following (but not mentioning) Potts in their work, Lim et al. [25] used a Potts-like model [31] to study how local violence leads to large-scale inter-ethnic conflicts. Somewhat similarly to this approach, the basic dynamics of our model [10] is the traditional voter process [15], in which at each iterative step every agent adopts the opinion of a randomly selected nearest neighbor. Thus the probability of accepting the opinion of the neighborhood is proportional to the number n of agents sharing that opinion [32]. A detailed review of the voter model is available in [15].

Axelrod model for the dissemination of culture [12], [13] describes a situation in which there is a global tendency of several distinct cultural states to stably coexist in spite of a dynamics of local convergence. An important novelty of this model is that it treats culture in a multidimensional way (and not as a binary variable), where interactions between many different cultural features play a crucial role. Thus, people can develop *Q* different opinions about *F* different topics, such as politics, age, sports, sexual orientation, movies etc. The visible advantage here is that the model allows for Q^F different opinion sets on all *F* topics [32]. Moreover, agents prefer to communicate with others with whom they share many opinions. More specifically, the probability with which an agent takes over the different opinion of a neighboring individual is proportional to the number of features on which their opinions are found to agree [32]. For further details on the Axelrod model and a comprehensive review, please consult Ref. [15].

SIMULATION SETUP

In agent-based simulations, both internal (e.g. behavioral) and external (e.g. political) mechanisms driving the dynamics of opinion formation are operationalized in terms of specific computational features and processes. Here, we outline the basic features included in our model. The algorithms for all simulations reported in the present study were written in FORTRAN and conducted on an UNIX-based computer system.

Population-wise, our model comprises of three strong minority groups with various affinities to each other, each having a possibility of selecting one out of three alternative opinions *A*, *B*, or *C*, at each iteration. A typical simulation of this type usually starts with a random or specifically defined initial distribution of the population subgroups consisting of e.g. up to several millions of agents. Opinion formation in the model works then in an iterative fashion by computing hundreds of thousands of different "evolutionary stages". In addition, a termination criterion is included in the algorithm to specify when the simulation should stop (e.g., the maximum number of iterations is defined).

Concentrations of individual agents belonging to different linguistic and/or political communities can be specified by different realistic criteria in the initial configuration (e.g., by considering realistic geopolitical maps). In our model, the population preferring the language choice *A* was set to occupy the top area of the simulated $L \times L$ lattice, covering approximately a total of 25% of the whole territory. We further assume that the simulated lattice is bordered on bottom by the population selecting the choice *C* (occupying another 25% of the total territory). Finally, in the middle of the lattice, the individuals voting for the choice *B* are dominant, occupying approximately 50% of the territories, thus representing the majority in the initial configuration of the lattice.

We conduct Monte Carlo simulations for different lattice sizes, different types of inter-group borders, different amounts of outside pressure (external influence), asymmetric internal noise distribution, and different migratory behaviors of individual agents. With larger lattice sizes (larger populations), it generally takes longer to compute the final outcome. More specifically, a power of the lattice size determines the total number of steps necessary to reach the consensus, with the exponent depending upon the dimensionality of the lattice [32]. The outside pressure corresponds to a particular type of an external influence on the system, e.g. in form of "advertising" [33] from some higher-level authority (e.g. United Nations). In order to mimic this influence in the present model, we assume that with some very low probability *p* each computational agent selects the opinion *B* at each generation, because of "advertising campaigns" in favor of *B*.

Moreover, the rather simple process of opinion formation, as outlined here, is not deterministic but instead driven by random fluctuations in an agent's switching behavior among several options over time. This stochasticity of the decision making behavior could be due to many reasons, including mixed relationships or marriages between agents with different opinions or other factors of latent origin. These effects can be incorporated by introducing a certain amount of internal noise into the model [27] where with some very low probability *q* at each iterative step each agent switches to another randomly picked option. In our simulation, just as in [10], agents with the opinion *A* switch to *B* three times more often than to *C* just as agents with the opinion *B* switch to *A* three times more often than to *C*. However, those agents preferring the choice *C* switch equally often to both *A* and *B*.

The reason for choosing the update rule of this kind is that we wish to describe a situation in which there is an additional political division between the territories occupied by the *C* population and the areas populated by *A* and *B* [10]. In such case, the simulated lattice could be viewed as separated into two major parts: On one side of the barrier *C* choice is dominant, while the populations preferring *A* and *B* choices have to share the rest of the territory across the other side of the border. In addition, the population preferring *B* choice is the only one in the model without fixed boundaries, while the other two are partially neighboring with two additional populations from which they occasionally receive some political support. Of course, many further details and variations can be included to achieve a higher degree of fine-granularity, since the presented generalization of the voter model is highly flexible with respect to its further modifications. For example, the additional effects of age, economic status and political conviction of individual agents can be added and modeled by a further extension à la Axelrod [12], [8], [10].

RESULTS

Without internal noise or outside pressure in the voter process, Fig.1 shows how the opinion of the majority (*B*) is reduced due to the effects of the fixed borders available for *A* and *C* populations only. The time required for the total decay of the *B* choice is delayed as the size of the lattice increases. The increasing curve for L = 501 depicts a special case scenario where the *B* opinion survives if the two fixed boundaries are now surrounding the *B* population, instead of *A* and *C*.

INSERT FIGURE 1 ABOUT HERE

If the fixed boundary for the population A is removed, then this leads to the dominance of a single opinion (Fig.2): C opinion is likely to win over B and A, but this is less pronounced for larger lattices (Fig.3). In Figs. 2 and 3, small amounts of internal noise and external pressure on the system are added.

INSERT FIGURE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

Fig.4 demonstrates that in the voter process, the time evolution of the three opinions first results in clusters (one time step is one update attempt per lattice site). Thus, agents with the same opinion prefer to be near each other. However, later, the opinion of the majority is substantially reduced until it is brought into a more stable state via internal noise and the external forces ("advertising"). When agents migrate i.e. switch their current locations with randomly selected agents placed anywhere in the lattice, the opinion B decays (Fig.5). This outcome is circumvented if agents migrate only once (thus, the outcome of this effect is almost identical to the case without any migrations).

INSERT FIGURE 4 ABOUT HERE

INSERT FIGURE 5 ABOUT HERE

The model shown in Figs. 1–5 is further expanded into a three-state three-trait Axelrod model [8], [10] with three binary variables which additionally influence the dynamics of opinion forming: money (rich or poor agents), age (young vs. old), and political orientation (leftists vs. rightists). In this generalization (Figs. 6–9), agents shift to the language choice of a randomly chosen neighbor if and only if they agree in at least one of the three aspects. In addition, we assume that older agents switch only half as often as young individuals, and ¾ of agents with opinions *A* or *B* are rich (and ¼ is poor), while the inverse is assumed for agents preferring the choice *C*. Results show the emergence of stable fragmented states at the global level in spite of a tendency towards local convergence (Figs. 6 and 9), yet different outcome variations are observed with different manipulations of physical and/or virtual inter-group boundaries and different lattice sizes (Figs. 7 and 8).

INSERT FIGURE 6 ABOUT HERE

INSERT FIGURE 7 ABOUT HERE

INSERT FIGURE 8 ABOUT HERE

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INSERT FIGURE 9 ABOUT HERE

CONCLUDING REMARKS

Sudden fragmentation or unification of languages may happen as an outcome of a variety of processes taking place at some highly critical stages of national evolution, e.g., during or immediately after an inter-ethnic conflict [5]. The inevitable emergence of novel opinions about the linguistic identity can then be seen as a response to this critical stage, and moreover, as a human natural tendency to sustain group cohesion and identity [34], [35] by modifying language choices in accordance with those principles that are most relevant for the survival of a culture.

In this paper, we studied the time evolution of language choices in a linguistically homogeneous but ideologically divergent community, where individuals can develop a set of different metalinguistic beliefs. We briefly reviewed our previous work [10] on opinion dynamics with a novel emphasis on the presence or absence of migratory processes, size effects, and cultural traits in combination with different types of physical and virtual inter-group boundaries.

In the simple voter model without noise and advertising, the opinion of the majority decays as long as the population remains without a fixed physical boundary. This effect is especially pronounced for smaller populations. However, as the population size increases, the survival period of the most dominant opinion extends. In addition, we demonstrated a critical importance of the fixed physical borders for populations of a moderate size. The removal of the physical border at e.g. one side induces the dominance of one single linguistic opinion in the model. This victory of a single language choice is less visible in larger lattices.

Somewhat contrary to our expectations, we discovered that after a sufficient number of iterations, the addition of noise had a stabilizing effect on the opinions of all three populations, despite the considerable reduction of the largest opinion that was observed in the initial “evolutionary stages”. Furthermore, when randomly selected pairs of agents exchange locations in the lattice, the opinion of majority dies out. However, this outcome of continuous migrations vanishes if only one migratory event is observed in the course of the simulation. In an Axelrod-type generalization of language choice dynamics we investigated the influence of social effects on opinion formation in various contexts. It was found that a global pattern of three stably coexisting language opinions (a multilingual state) emerges even if there is an evidence of convergent behavior at the local level.

Our computational study also shows that agents can quite quickly adapt their linguistic opinions to those of others in the neighborhood as the rapid imitation [15] of novel communication systems becomes necessary for the survival of a culture. Future research directions should address the possibilities of extending opinion dynamics and other related computational models in a more realistic fashion. For example, at the structural level, instead of simple lattices, complex network models could be used to study the co-evolution of the network and voter states. By including more realistic traits, agent-based computer simulations can develop into important and genuinely predictive tools, and may thereby considerably help in advising language policy makers. However, future research should also better bridge the gap between experiments and models (for purposes of model validation), and pay more attention to the sophistication of internal representations of individual agents [36]. It is here that computational and social scientists must work together by concentrating on new approaches capable of reproducing realistic datasets and involving more structural fine-details of the investigated languages or opinions in competition.

Similarly to the study of Lim et al. [25], we observed the effects of unstable and fuzzy inter-group boundaries, however, differently from their tentative proposal (imposed mixing or clear separation of ethnically diverse populations as mechanisms for promoting peace), we argue that symbolic tradeoffs, most importantly, understanding and acknowledging other groups' linguistic traditions and related ethnicity-specific values, may help to circumvent or resolve even seemingly intractable and long-standing conflicts [37], [38]. It is therefore a challenge for future research to better understand the evolution of fairness in opinion dynamics [39] and sacred-like values [37] in a society which is linguistically homogeneous but politically divided.

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FIGURE LEGENDS/CAPTION TEXT

Fig.1: Number of B choices as a function of time in the voter model without internal noise or external pressure effects (“advertising”). The size of the respective lattices is increasing from left (101^2) to right (1001^2).

Fig.2: C choice (x) is likely to win over A (+) and B (*) if A loses its rigid boundary. For small lattices, such as here for 201^2, this victory is more visible, but the effect diminishes with the increasing size of the lattice.

Fig.3: For a larger lattice, such as here for 1001^2, the victory of C choice (x) is less pronounced, and C is now competing for victory with B.

Fig.4: Snapshots of the time evolution of opinions for a lattice size $L = 400 \times 400$ at times t=100 (left) and t=100000 (right), with small internal noise and small advertising $p=q=10^{-5}$.

Fig.5: The evolution of the B choice over time in a 1001^2 lattice: Without (+), with (x), and with one single (*) migration.

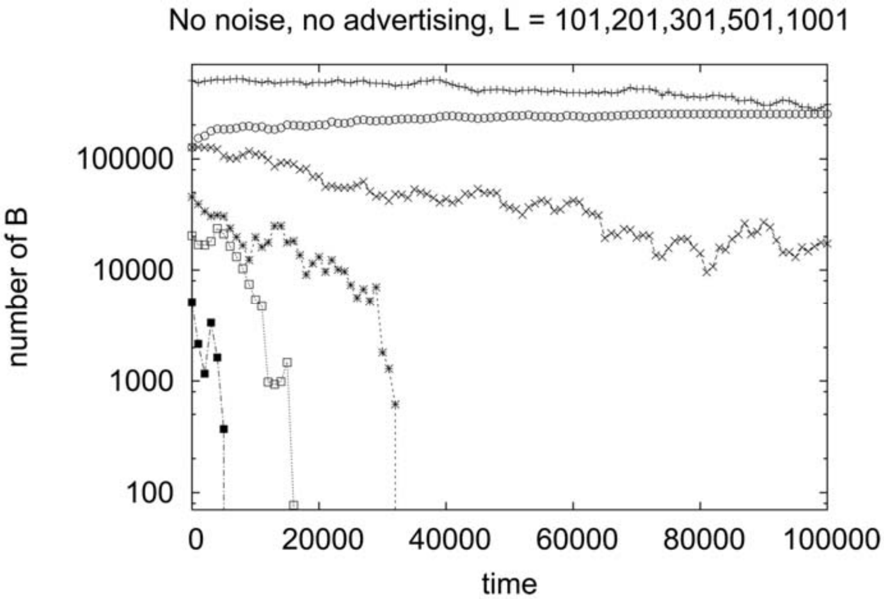
Fig.6: Axelrod-like model generalization in a 1001^2 lattice with 3 binary features (money: rich vs. poor, age: old vs. young and political orientation: right vs. left). Agents choosing the option C (*) are set to be poorer in this simulation than those preferring the linguistic options A (+) and B (x).

Fig.7: Axelrod-like model generalization in a 501^2 lattice with 3 binary features: With (+) and without (x) a fixed physical boundary (results displayed for B choice only). There is no exchange of opinions between A and C (*), which was set to simulate the effects of a virtual boundary between the groups

Fig.8: Axelrod-type generalization in a 501^2 lattice with 3 binary features (age, money, and politics), and without fixed boundaries (shown for all populations).

Fig.9: Axelrod model generalization in a 1001^2 lattice, with a virtual (political) boundary between A and C (there is no exchange of opinions between A and C).

LIST OF FIGURES



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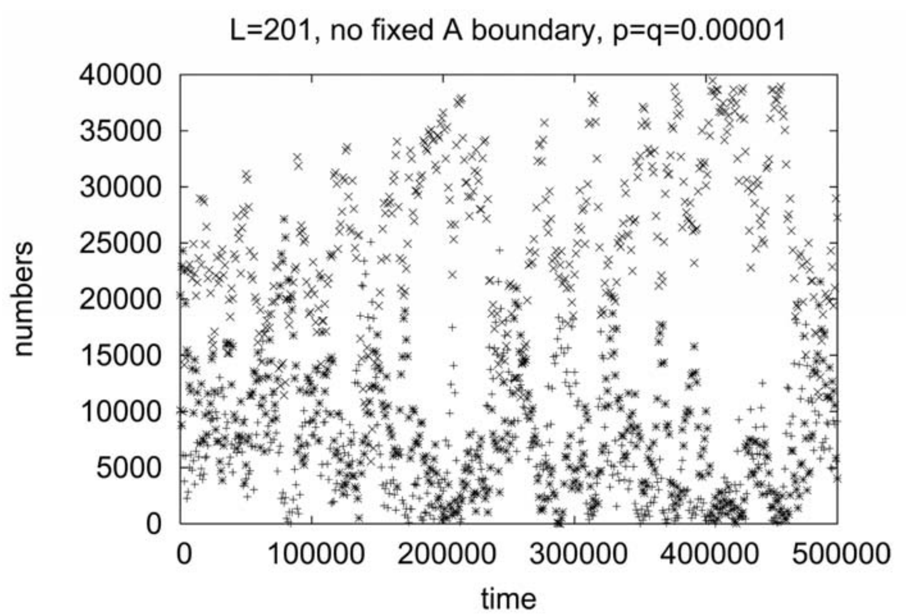

Fig.2

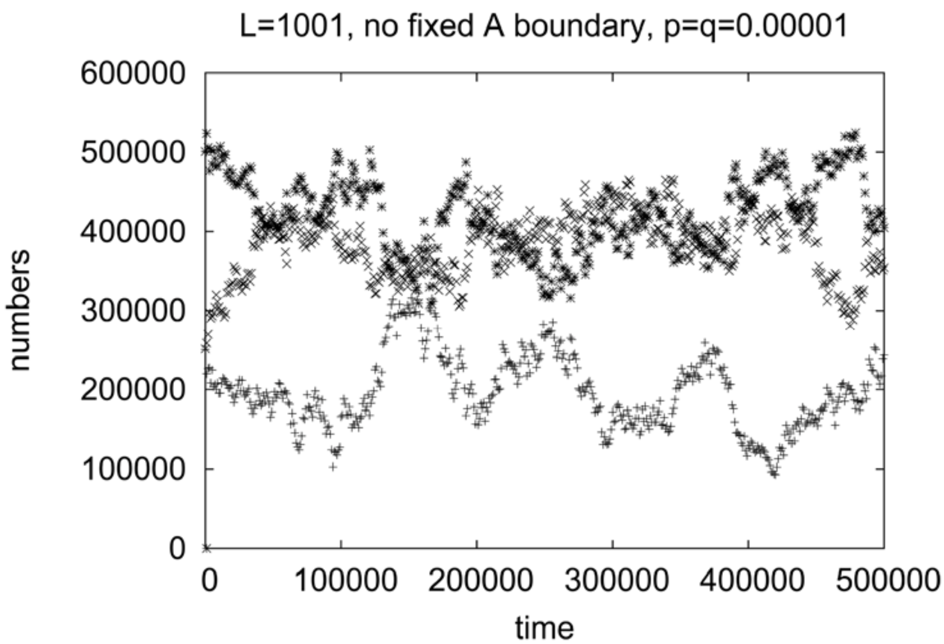

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Fig.3

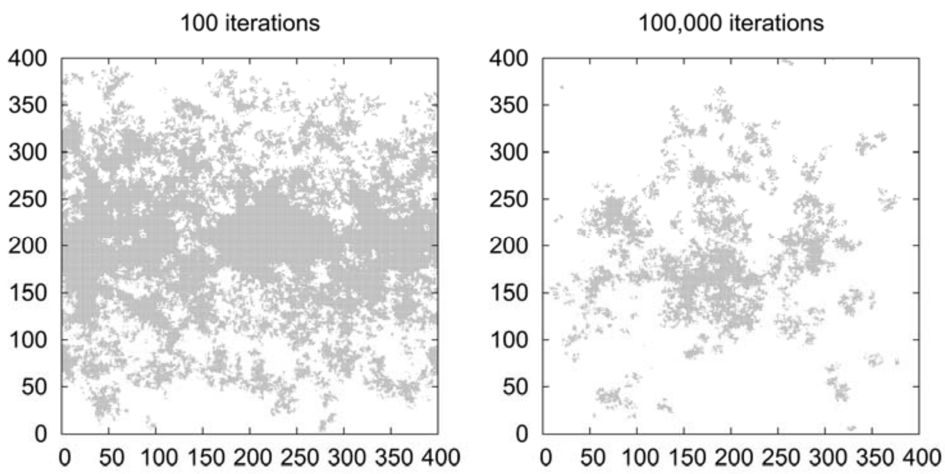

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Fig.4

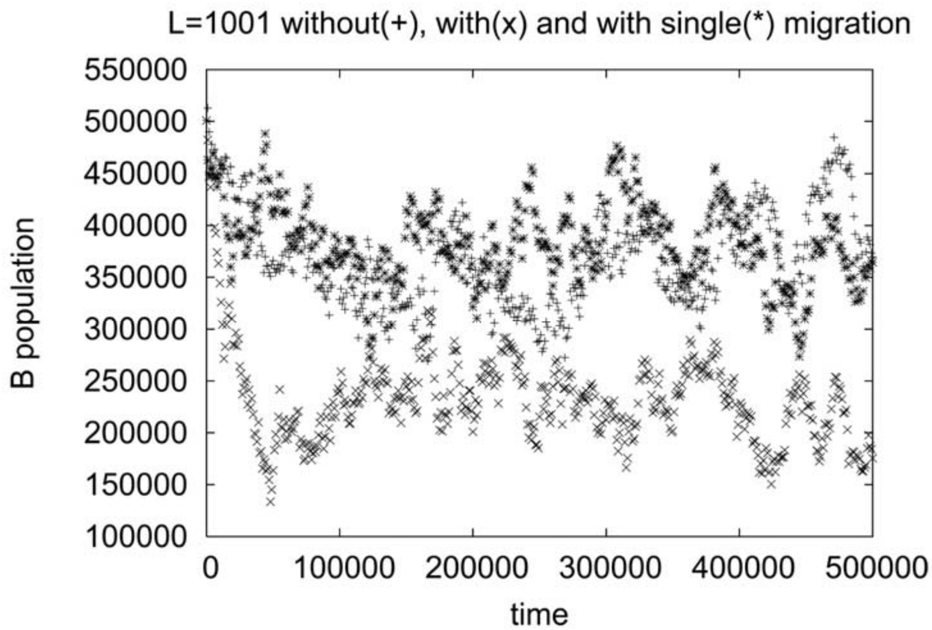
L=1001 without(+), with(x) and with single(*) migration
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Fig.5

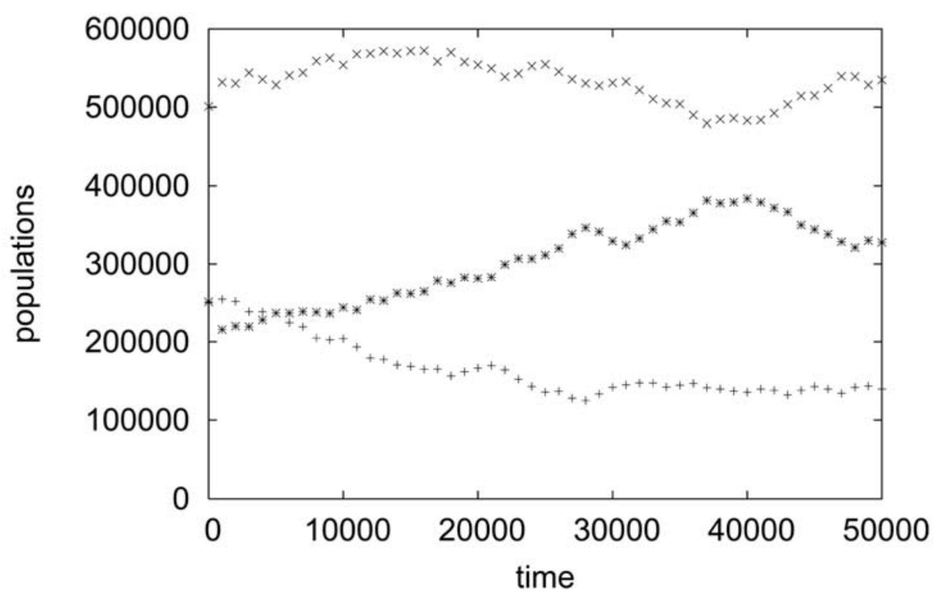
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Fig.6

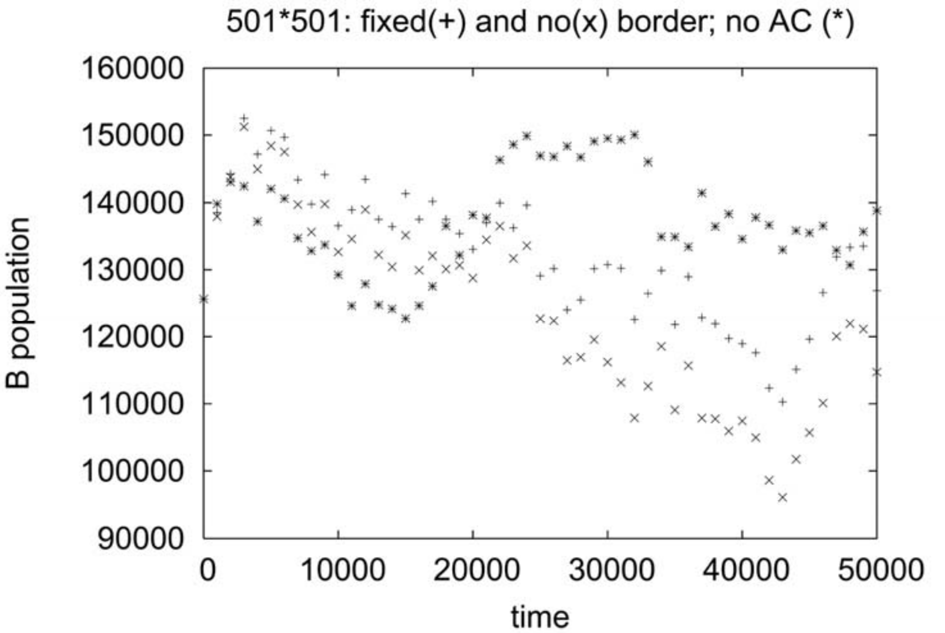
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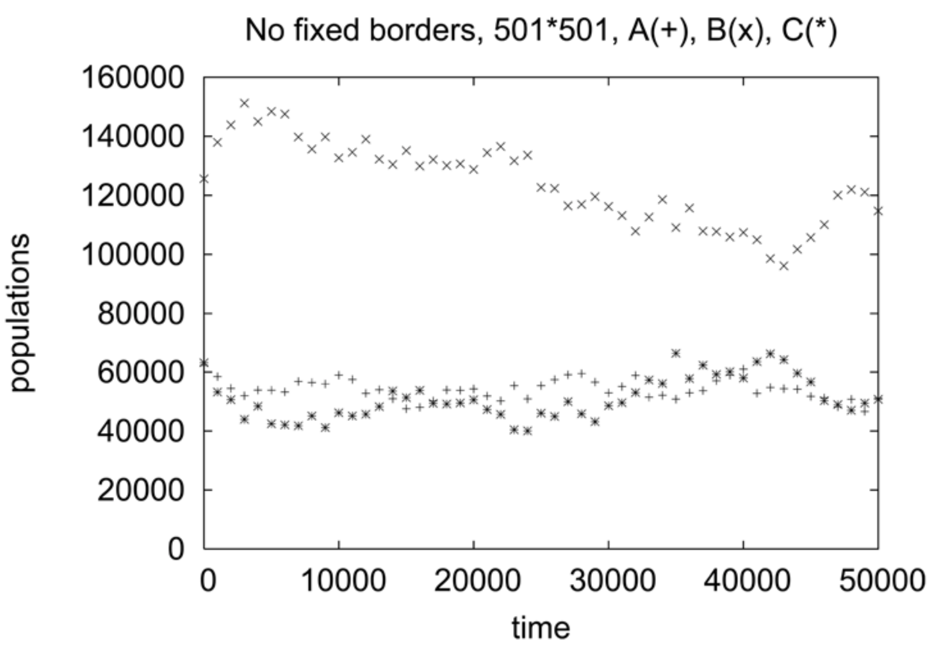
Fig.7


No fixed borders, 501*501, A(+), B(x), C(*)
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20000
0
0
10000
20000
30000
40000
50000
time

Fig.8

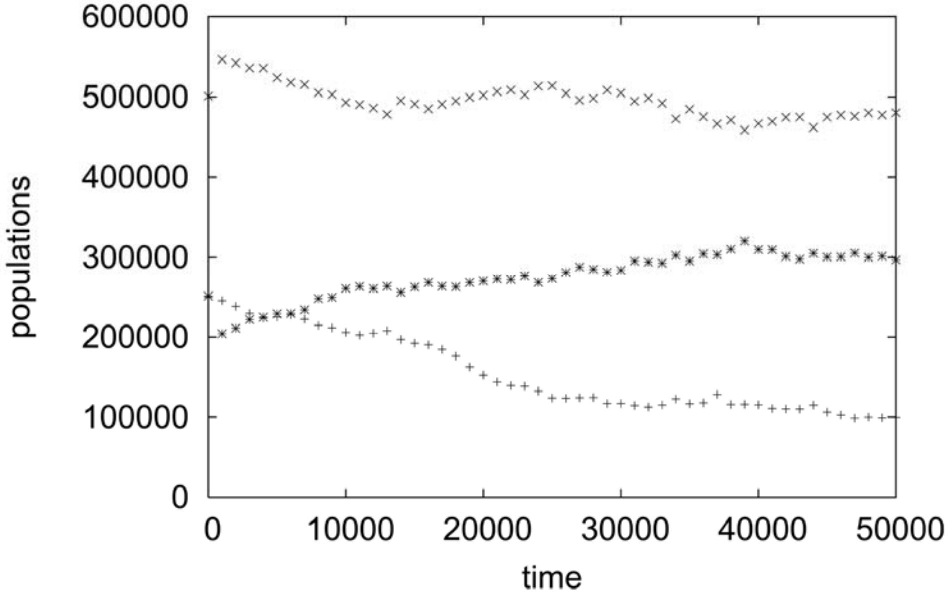
600000
500000
400000
300000
200000
100000
0
populations
0
10000
20000
30000
40000
50000
time

Fig. 9