Modelling bilingualism in language competition: the effects of complex social structure

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Abstract. In the general context of dynamics of social consensus, we study an agent based model for the competition between two socially equivalent languages, addressing the role of bilingualism and social structure. In a regular network, we study the formation of linguistic domains and their interaction across the boundaries. We analyze also the dynamics on a small world network and on a network with community structure. In all cases, a final scenario of dominance of one language and extinction of the other is obtained. In comparison with the regular network, smaller times for extinction are found in the small world network. In the network with communities instead, the average time for extinction is not representative of the dynamics and metastable states are observed at all time scales.

1 Introduction

Language competition belongs to the general class of processes that can be modelled by the interaction of heterogeneous agents as an example of collective phenomena in problems of social consensus [1]. In this respect, a specific feature of language dynamics is that agents can share two of the social options that are chosen by the agents in the consensus dynamics. In the present work, these are the bilingual agents, that is, agents that use both language A and B, who have been claimed to play a relevant role in the evolution of multilingual societies [2].

In this work we are interested in the emergent phenomena appearing as a result of a self-organized dynamics in the case of two equally prestigious competing languages. With the aim of elucidating possible mechanisms that could stabilize the coexistence of these languages, we wish to discuss the role of bilingual individuals and social structure in the process of language competition. To this end, and along the lines of the original proposal by Minett and Wang [2], we study an agent based model that incorporates bilingual agents on different networks: a regular lattice, a small world network, and a social type network with community structure [3]. We compare the results obtained with the agent-based version [4] of Abrams-Strogatz two-state model [5], where bilingualism was not taken into account.

2 The Bilinguals Model

We consider a model of two socially equivalent (i.e. equally prestigious) competing languages in which an agent i sits in a node within a network of N

individuals and has k_i neighbours. It can be in three possible states: A, agent using [1] language A; B, agent using language B; and AB, bilingual agent using both languages, A and B.

The state of an agent evolves according to the following rules: at each iteration we first choose one agent i at random, and, then, we compute the local densities of language users of each linguistic community in the neighbourhood of agent i: σ_i^l (l=A, B, AB; i=$1, N$; $\sigma_i^A + \sigma_i^B + \sigma_i^{AB} = 1$). The agent i changes its state of language use according to the following transition probabilities [2]:

$$p_{i,A\to AB} = \frac{1}{2}\sigma_i^B \ , \qquad p_{i,B\to AB} = \frac{1}{2}\sigma_i^A \tag{1}$$

$$p_{i,AB\to B} = \frac{1}{2}(1-\sigma_i^A) \ , \qquad p_{i,AB\to A} = \frac{1}{2}(1-\sigma_i^B). \tag{2}$$

Equation (1) gives the probabilities for an agent to move away from a monolingual community to the bilingual community AB. They are proportional to the density of monolingual speakers of the other language in its neighbourhood. On the other hand, equation (2) gives the probabilities for an agent to move from the bilingual community towards one of the monolingual communities. Such probabilities are proportional to the density of speakers of the adopting language including bilinguals ($1-\sigma_i^l = \sigma_i^j + \sigma_i^{AB}$, l, j=A, B; $l \neq j$). It is important to note that a change from being monolingual A to monolingual B or vice versa always implies an intermediate step through the bilingual community. The transition probabilities (1) and (2) are fully symmetric under the exchange of A and B, which is consistent with the fact that both languages are socially equivalent in terms of prestige.

We recover the agent-based version of Abrams-Strogatz two-state model when bilinguals are not present [4]. In this model, an agent essentially imitates language use of a randomly chosen neighbour.

For a quantitative description of the emergence and dynamics of linguistic spatial domains we use the ensemble average interface density $\langle\rho\rangle$ as an order parameter. This is defined as the density of links joining nodes in the network which are in different states [1]. The ensemble average, indicated as $\langle\cdot\rangle$, denotes average over realizations of the stochastic dynamics starting from different random distributions of initial conditions. During the time evolution, the decrease of ρ from its initial value describes the ordering dynamics, where linguistic spatial domains, in which agents are in the same state, grow in time. The minimum value $\rho = 0$ corresponds to a stationary configuration in which all the agents belong to the same linguistic community.

3 Results

a)*Regular and small world networks*

[1] Note that we always refer to language use rather than competence.

[2] Non-equivalent languages were considered in the original version of the model [2]. The prefactor 1/2 corresponds to the special case of equivalence between A and B.

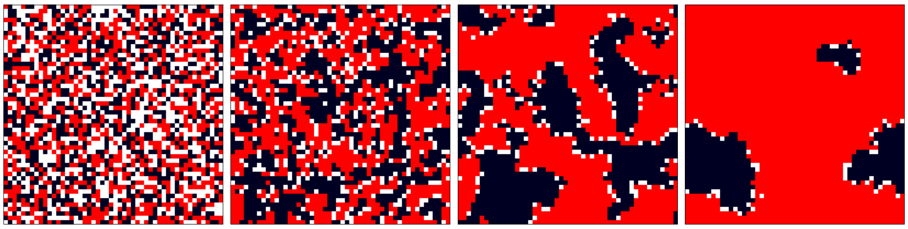

Fig. 1. Random initial conditions: snapshots of a typical simulation of the dynamics in a regular lattice of 2500 individuals. t=0, 2, 20, 200 from left to right. Red: monolinguals A, black: monolinguals B, white: bilinguals.

The bilinguals model has been extensively studied in two-dimensional lattices, and small world networks [6]. In two-dimensional lattices, and starting from a randomly distributed state of the agents, spatial domains of each monolingual community are formed and grow in size (Fig 3). This is known in the physics literature as *coarsening*. Meanwhile, domains of bilingual agents are never formed. Instead, bilingual agents place themselves in a narrow band between monolingual domains (Fig 3). Finally a finite size fluctuation drives the system to an absorbing state, where all the agents become monolingual, while the other monolingual community together with the bilingual agents face extinction. Average interface density $\langle\rho\rangle$ decays as a power law $\langle\rho\rangle \sim t^{-\gamma}$, $\gamma \simeq 0.45$ [6]. This indicates that the growth law found for the bilinguals model is compatible with the well known exponent 0.5 associated with domain growth driven by mean curvature and surface tension reduction observed in SFKI (spin flip kinetic Ising model) [7]. The characteristic time to reach an absorbing state τ scales with system size as $\tau \sim N^{1.8}$. A very different behaviour is found for the agent based Abrams-Strogatz model, where bilingual agents are not present: coarsening is slower ($\langle\rho\rangle \sim \ln t$) and driven by interfacial noise.

In Watts-Strogatz small world networks $\tau \sim \ln N$ [6]. While for the agent based Abrams-Strogatz model the long range connections inhibit coarsening by producing long-lived metastable states, in the bilinguals model adding long range connections to the two-dimensional lattice slows down coarsening, but domains keep growing in size. In addition, they speed up the decay to an absorbing state due to finite size fluctuations [6].

b) *Social type network with community structure*

A combination of random attachment with search for new contacts in the neighbourhood has proved fruitful in generating cohesive structures (algorithm in [3]). We choose this model, which produces well-known features of social networks, such as assortativity, broad degree distributions, and community structure.

The most important result regarding this topology, is the behaviour of the characteristic time to reach an absorbing state. To this end, we analyze the fraction $f(t)$ of runs still alive at any time t, i.e. the fraction of runs which have not reached the absorbing state. We average over different realizations of the network, and several runs in each. For the agent based Abrams-Strogatz model, the fraction of alive runs decreases exponentially. Results are more interesting for the bilinguals model: $f(t)$ appears to have power law behaviour $f(t) \sim t^{-\alpha}$, $\alpha \approx 1.3$. Since the exponent $\alpha < 2$, the average decay time for the bilinguals model does not give a characteristic time scale, but alive realizations which have not reached the absorbing state are found at any time scale. Analyzing these simulations, we observe configurations of language domains in which one of the monolingual communities has nearly taken over the whole system, while the domain of the minority language eventually only resides in small communities which are loosely connected to the rest of the network. Bilingual agents remain at the interfaces between domains. These facts indicate correlation between community structure and linguistic domains. As the bilinguals model is effectively a majority rule (SFKI), these configurations lead to metastable states.

4 Conclusion

We have analyzed the bilinguals model (in comparison to the agent-based version of Abrams-Strogatz model) in different topologies. Although the final state of the system is always an homogeneous state where one of the languages faces extinction, the transient towards this final state depends crucially on the network structure. Within the limitations and assumptions of the model, the study of the dynamics in the social type network with communities shows that there exist metastable states at all time scales; indicating that in presence of bilingual individuals, minority languages might survive for very long periods when the social network displays community structure.

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