DYNAMICS OF LANGUAGE COMPETITION:

EFFECTS OF BILINGUALISM AND SOCIAL STRUCTURE

Xavier Castelló, Víctor M. Eguíluz and Maxi San Miguel

IMEDEA (CSIC-UIB), Ed. Mateu Orfila, Campus Universitat Illes Balears, E-07122 Palma de Mallorca, Spain.

1. INTRODUCTION:

Studies of the dynamics of human language can be divided into three main groups, depending on their specific point of view: *Language Evolution, Language cognition* and *Language competition*. The first one treats language as a complex system itself, studying language structure dynamics from the point of view of linguistics and human evolutionary theory. The second one analyzes languages acquisition, mainly centred in the study of human brain learning processes and genetics. Finally, *language competition*, the field we address here studies the dynamics of language use and learning due to social interactions. As such it is a process belonging to the general class of processes that can be modelled by the interaction of heterogeneous agents.

Many countries have different languages coexisting today within their boundaries, but the fate of many of them in the future is today unclear. The dynamics underlying processes of language competition and extinction has been considered from the point of view of complex systems of interacting agents [1]. Starting from the model of Abrams and Strogatz for the dynamics of endangered languages [2], the models proposed by Mira and Paredes, and Minett and Wang [3] address the issue of bilingualism.

Our main goal in this work is to contribute to gives answers to the general questions about the *dynamics of language use*: which are possible mechanisms to stabilize the coexistence of two competing languages? Which is the role of bilingual individuals and social structure in this process?

In particular we study the effects of locality on the competition between two languages in a social structure, going beyond previous mean field analysis. The mechanisms of growth of monolingual spatial domains, the dynamics at the linguistic borders, and the role of bilingual individuals in processes of domain growth, are also analyzed. Finally, we address the effect on the dynamics of the degree of disorder in the social network [4], and the possibility of metastable states of coexisting languages.

2. THE MODEL:

In the general context of the work by Minett & Wang, we consider a model 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 belonging to the monolingual community using language A; B, agent belonging to the monolingual community using language B; and AB, agent belonging to the bilingual community using both languages, A and B.

A parameter in the model is language status, s_i, (i=A,B). This parameter represents the prestige of a language and the social benefits for the agent who speaks it (access to culture, personal and professional development, international communication,...). The maximum value for status is 1, and the minimum 0. Status of the two languages are related such that: $s_A + s_B = 1$.

The state of a node evolves according to the following dynamics: starting from random initial conditions (random spatial distribution of 1/3 of A users, 1/3 of B users and 1/3 of bilingual individuals), at each iteration we choose one agent i at random and we compute the local speaker densities σ_i ,(i=A, B, AB), which are the densities of language users of each community in the neighbourhood of node i. The agent changes his state of language use according to the following transition probabilities proportional to the local density of speakers of each language community, and to the language status of each language:

$$
\begin{aligned}
p_{A \to AB} &= s_B \cdot \sigma_B \\
p_{B \to AB} &= s_A \cdot \sigma_A
\end{aligned}
\qquad (1)
$$

$$
\begin{aligned}
p_{AB \to A} &= s_A \cdot (\sigma_A + \sigma_{AB}) \\
p_{AB \to B} &= s_B \cdot (\sigma_B + \sigma_{AB})
\end{aligned}
\qquad (2)
$$

Eq. (1) gives the probabilities for an agent to move away from the monolingual community i to the bilingual community AB. They are proportional to the density of monolingual speakers of the other language j in her neighbourhood, σ_j, and to the status s_j of language j (i,j= A,B). Eq. (2) gives the probabilities for an agent to move from the bilingual community towards a monolingual community i (i=A,B). They are proportional to the density of speakers of language i (including bilinguals), $\sigma_i + \sigma_{AB}$ and to the status s_i of language i (i,j = A,B). It is important to note that a change from being monolingual A to monolingual B community or vice versa, always implies an intermediate step through the bilingual community.

As a first step, we only consider in this work the case of two socially equivalent languages i.e., $s_A = s_B = 0.5$. We use asynchronous update and a unit of time includes N iterations: each node has been updated on average once in a unit of time. An analysis of the mean field equations shows the existence of three fixed points: two of them stable and equivalent, corresponding to states of monolingual dominance of one of the languages and the extinction of the other communities; and another one unstable, where all three communities are present.

To describe the ordering dynamics associated with the emergence of spatial domains of the linguistic communities we use as an order parameter an ensemble average interface density $<\rho>$ defined as the density of links joining nodes in the network belonging to different states. $\rho = 0$ characterizes an absorbing state of the system, where all agents use the same language.

3. LOCAL EFFECTS IN A REGULAR LATTICE.

We first consider the dynamics on a 2-dimensional regular lattice with four neighbours per node. We observe in Fig.1 the evolution of the system for a typical realization: language A takes over the system, while language B faces **extinction** (languages are socially equivalent, thus B faces extinction with probability ½). We observe an early very fast decay of the interface density and of the density of bilingual speakers σ_{AB}, followed by a stage of fluctuations around a small value until one of the languages starts to dominate, and the bilinguals disappear together with the language that faces extinction.

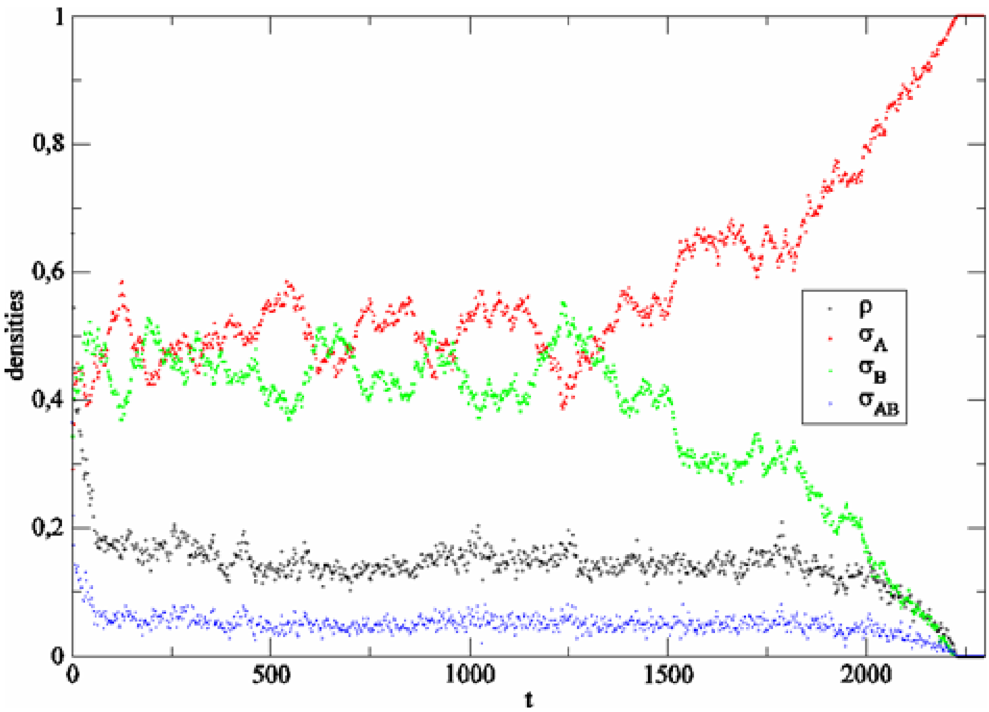

Fig. 1. Typical realization of the dynamics for a system of N=400 agents.

Fig.2 shows the evolution of the average interface density and the bilingual community density in time. For the relaxation towards one of the absorbing states we obtain a power law for the decay of the averaged interface density: $<\rho> \propto t^{-0.45}$. The power law for the decay of the density of bilinguals has the same exponent: $<\sigma_{AB}> \propto t^{-0.45}$ This indicates that the evolution of the density of bilinguals is directly connected with the dynamics of interfaces.

Simulations of the temporal evolution of the spatial distributions of the agents show that monocultural domains are formed as a result of a coarsening process, while bilingual domains are never formed. During an early fast dynamics bilinguals place themselves in the interfaces between the two monolingual communities. This explains the finding that the bilingual density follows the same power than the density of interfaces. For the growth law of the characteristic length of a monolingual domain we find an exponent near 0.5, $l(t) \propto t^{0.45}$. Therefore domain growth seems to be governed by curvature effects, at variance of what happens in other imitation dynamics in which interfacial noise dominates [5].

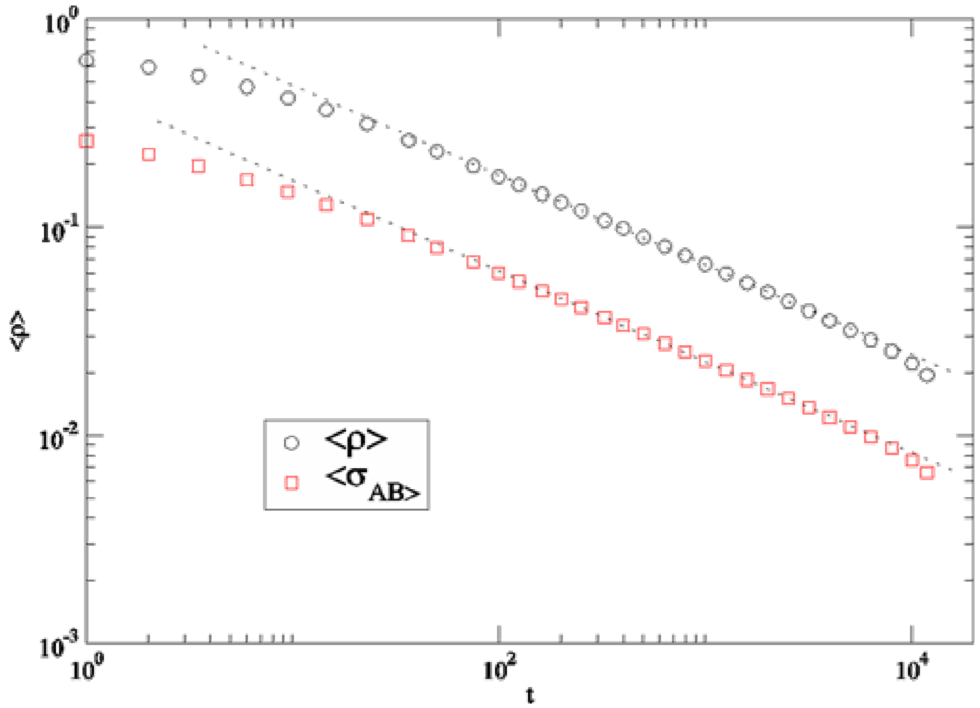

Fig. 2. Time dependence of average interface density and density of bilinguals for a system of N=10000 agents. Averages are over 1000 independent realizations.

Our simulations also provide evidence of the intrinsic instability of bilingual communities: An initial bilingual domain disintegrates very fast into monolingual domains, and bilinguals just appear at the interfaces. Therefore, it follows from the present model that societies with knowledge of two languages tend to end up using just one of them, even if they are ideally socially equivalent. The role of bilinguals is to link different monolingual domains, being able to communicate with both of them, but eventually disappear.

4. SOCIAL STRUCTURE: Dynamics in a Small World Network

We next consider the dynamics of language competition on a small world network constructed following the algorithm of Watts & Strogatz [6], where p is the probability of rewiring.

Fig.3 shows the evolution of the mean interface density for different values of p: i) In the range of intermediate values of p corresponding to a small world network a plateau associated with a metastable state is reached. In this sate language coexistence lasts for a finite time with a density of bilinguals around 10%, and the monolingual domains having similar size. ii) The plateau value of $<\rho>$ increases when increasing p, as well as the density of bilinguals in the metastable state. iii) The metastable state decays due to finite size fluctuations. The lifetime of the metastable state decreases when increasing the rewiring parameter p.

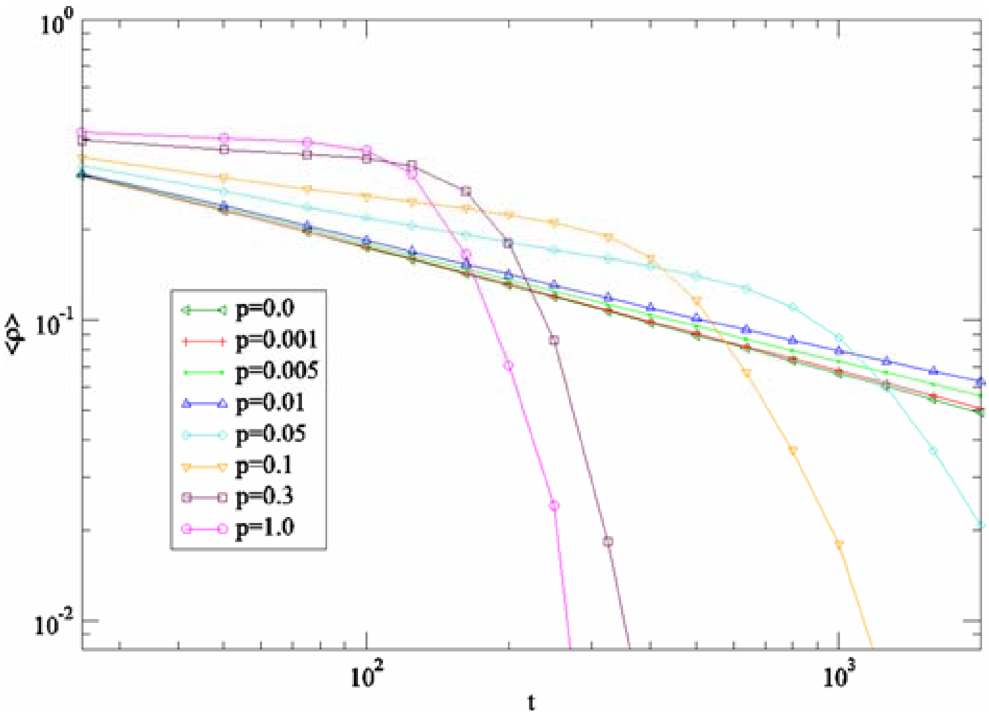

Fig. 3. Time dependence of average interface density for a small world network with N=40000 agents. Averages are over 100 independent realizations.

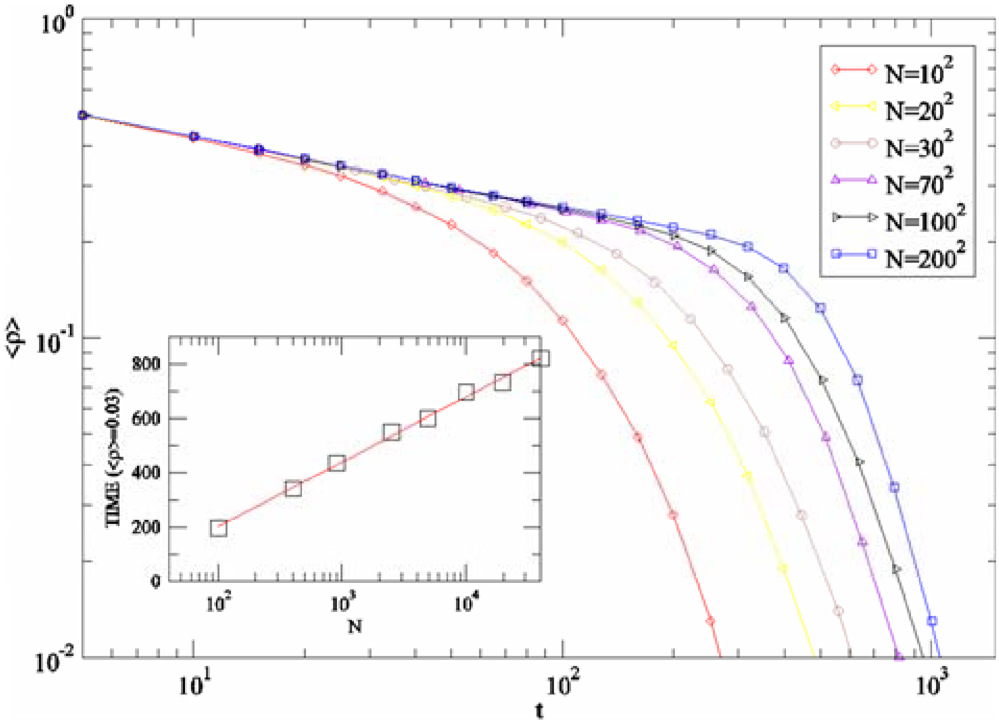

Fig. 4. Time dependence of average interface density for small world networks with rewiring parameter p=0.1 and varying number of agents from N=100 to N=40000 Averages are over 1000 realizations, in 10 different networks.

The implications of different system sizes in the metastable reached in a small world are shown in Fig. 4. We observe that the plateau value of <ρ> is grossly independent of system size, but the lifetime of the metastable state scales with system size as $\tau \propto \ln N$. Therefore, a small world network stabilizes language coexistence in metastable states with a lifetime that diverges with system size. An important point is the nature of these metastable states. They are *macroscopic* states that do not originate in configurations with frozen dynamics. At the microscopic level, individuals agents continue to change their state, keeping averaged properties constant in time.

6. CONCLUSION:

Within the assumptions of the model discussed here, with linear transition probabilities (proportional to densities of speakers), bilingualism and social structure are not efficient mechanisms to stabilize language coexistence in a finite population. However, in small world networks, a metastable state is reached, giving rise to scenarios of long-lived coexistence of the two languages in large systems.

References:

[1] Schulze, C., Stauffer, D. (2005), *Microscopic and macroscopic simulation of competition between languages* Physics of Life Reviews **2**, 89; *Simulation of language competition by physicists,* cond-mat/0511049.
[2] Abrams, D.M., Strogatz, S. H. (2003), Nature **424**, 900.
[3] Mira, J., Paredes, A. (2005). Europhysics Letters **69**, 1031; Minett, J. W., Wang, W. S-Y. (unpublished).
[4] Suchecki, K., Eguíluz, V. M. , and San Miguel, M. (2005) *Voter model dynamics in complex networks: Role of dimensionality, disorder and degree distribution* Physical Review E **72,** 036132 (1-8)
[5] San Miguel, M., Eguíluz, V. M., Toral, R., and Klemm, K. (2005) *Binary and Multivariate models of consensus formation.* Computing in Science and Engineering **7**, 67.
[6] Watts, D. J. Strogatz, S.H. (1998), Nature **393**, 440