Modeling combined phonological and lexical change of two linguistic communities through social interaction

Ioannis Vagias, Elpida Tzafestas

Cognitive Science Laboratory
Department of Philosophy and History of Science
University of Athens University Campus, Ano Ilisia 15771, Athens, Greece
ivagias@phs.uoa.gr, etzafestas@phs.uoa.gr

Abstract. In this work, we are presenting a simple model of combined linguistic change at the phonological and at the lexical level. We experiment with the model by using agent-based simulation: two groups of agents that speak initially different languages interact through participation in different social activities. It is shown that the lexicon size initially grows and later shrinks as the agents converge to a monolingual configuration. The final language that emerges is determined by the relative percentage of the two populations initially, since this percentage defines the average frequency of interactions. Thus always the dominant language is the one of the majority, in the sense that the words of the final language are closer to or even copied from the language of the majority. Variations in the structure of interaction between the two groups will lead to a linguistic mix. The addition of a new parameter, called intensity of interaction, and expressing differential attention to different speakers, may revert these tendencies and yield languages where the language of a minority may finally dominate, such as in a realistic master-slave scenario where the dominant language is the master's language independently of relative size of the two populations.

1 Introduction

Simulated evolution of language is concerned with understanding, among other things, the factors and the evolutionary forces that are responsible for the appearance of human language as well as for the dynamics of language change at the macro or population level [1]. Studies in simulated evolution of language borrow the methodological concepts and tools that have been developed for the study of biological evolution [2][3]. Thus simulated evolution of language is interested in issues such as the direction of language change, the sources of linguistic variation, the environmental pressure that biases and directs certain developments and the evolution of linguistic complexity [4][5]. It is generally believed that languages decline, for example the three fundamental ancient indoeuropean languages (ancient greek, classical latin and sanskrit), that are by now extinct, were many orders of magnitude more complex than their modern counterparts and descendants. On the other end of the globe, in southeastern Asia, the vietnamese language has replaced Chinese Han characters with a special version of the latin alphabet and the korean language is steadily restricting the use of the chinese-derived hanza characters in favor of the much simpler Hangul alphabet. Therefore, it comes as no surprise that such observations have led to the common layman belief of complexity decrease. But, if one adopts the biological paradigm, then he will be rather brought to expect that linguistic complexity should rise, in the same sense that biological complexity is supposed to have risen from the ancestor minimal organisms to the multi-faceted, extremely complex organisms that we know of today, the human being the most prominent of them. However, the issue of linguistic complexity is by far not consensual. First of all, there exist many definitions of linguistic complexity and many debates over the role of typological comparison and criteria of judgment [6]. Linguistic complexity invariance has been for long an axiomatic assumption in linguistics, but is now an object of serious doubt and refutation attempts [7][8]. Furthermore, unlike the biological domain, not all or most linguists would agree on a common linguistic ancestor or a proto-language [9]. One of the principal forces driving complexity change and linguistic evolution has been proposed to be population and language contact [10][11]. A study of language change dynamics and linguistic complexity could shed more light on issues such as linguistic speciation and creolization, the role of emergence of syntax or grammar etc. Phenomena of language change via population contact have been studied with agent-based simulation, for example Satterfield [12] has tested the hypothesis of incomplete second language learning in a creole environment, Beltran et al. [13] have studied language shift from a subordinate to a dominant language and Castelló et al. [14] study bilingualism and linguistic competition in a social network.

We construct a model of language change at both the lexical level (as in [13][12]) and the phonological level (as in [15]) so as to have a more realistic two-factor device than the simple monofactor lexical one. We perform experiments with a population of agents of two distinct initial linguistic origins to capture the dynamics of two populations that meet. Our long term goal is to examine whether linguistic complexity may move in any direction, up or down, from any point and under which circumstances. In what follows, we examine the simple two-population scenario in an attempt both to understand when and why one of the languages dominates and to draw conclusions on the internals of the linguistic device that would support these phenomena. In section 2, we present the linguistic model and we explain its function. In section 3, we describe the simulations performed and in section 4 we present the experiments and discuss the results obtained. Finally, in section 5 we conclude and give some directions of future research.

2. Model of Language Change

We have developed a simple computational model to simulate language change through contact of different language cultures. In our language change model a population of agents of two types (*type0*, and *type1*), participates in three types of social activities (activity0, activity1, activity2). All agents are equipped with a language device composed of a phonological and a lexical module.

2.1 The artificial language

The basic phonological unit of the language is the syllable, which is composed by two phonemes, one consonant and one vowel. The phonological module core component is the phonological matrix which associates every pair of phonemes (a vowel i and a consonant j) through a weight (a real number from 0 to 1) which represents the probability that the specific phoneme combination exists in the language (*phonologicalStrength*). A word is composed of one or more syllables, and is associated in the context lexicon with each social activity through a probability that the word can be used in the social activity (*contextStrength*). The context lexicon is created with a predefined size (*lexiconSize*) for each activity (context), but grows and shrinks during interaction.

2.2 Social activities

There are three types of activities: type0-only, type1-mandatory, and type1-free, where the participation of type1 agents is forbidden, mandatory and voluntary respectively. This scenario has been conceived so as to capture a breadth of interaction contexts, the most prominent being the paradigmatic master – slave world, where type0 agents are the masters and type1 are the slaves. At each computational cycle agents are selected at random to participate in a randomly selected activity, some of them as speakers, the others as listeners.

2.3 Agents Interaction

When an agent is selected as speaker, a word from the agent’s context lexicon is selected at random, and if its contextStrength is greater than a predefined threshold

(*LThresh*), then it is fed as input to all the other agents who participate in the activity (listeners), and lexical learning takes place (see below).

A listener executes in two steps: First, for each syllable of the input it checks if the phonologicalStrength of the combination of the syllable's phonemes exceeds a predefined threshold (*PThresh*). If it does, the syllable is selected, otherwise, a search for a close combination whose phonologicalStrength is greater than the threshold is performed. Phonological learning (see below) takes place twice: once in the beginning of the process, to learn the phonology of the raw input and once in the end, to learn the phonology of the step-1-processed input. Secondly, a search for the processed phonological input is performed in the context lexicon, for the specific context value, and if it is not found, it is added (with contextStrength=0). Lexical learning is performed to learn the word that was either found or just added.

Table 1. Algorithm for the simulation cycle

```
random selection of activity
random selection of participants, based on activity rules
random selection of speakers from the participants
for the number of speakers
 word=speakers[i].speak()
  for the number of participants
   if (j!=i)
      participant[j].listen(word)
```

Table 2. Algorithm for the listener

```
procedure listen(phonoInput)
  // step1 : phonological processing
  //loop1
  foreach syllable in phonoInput
    //phonological learning of the raw input
    executePLearning(syllable)
    if (syllable phonological strength > PThresh)
      //phonological learning of the perceived input
      executePLearning(syllable)
    else
      //loop2
      foreach new_syllable in the four closest vowel-consonant
combinations //(see table 5)
         if (new_syllable phonological strength > PThresh)
           //phonological learning of the perceived input
           executePLearning(new_syllable)
           exit foreach-loop2
         else continue
  // step2 : lexical processing
  executeLLearning(step1ProcessedInput)
```

2.4 Learning mechanisms

Lexical learning is accomplished by increasing contextStrength of the target word for the specific activity by a predefined value (*LRate*) and by decreasing the contextStrength of the other words for the same activity by a predefined value (*LInRate*).

Phonological learning is accomplished by increasing the phonologicalStrength of all syllables of the phonological input by a predefined value (*PRate*), and by decreasing all the other phonologicalStrengths of all the combinations of the specifics vowels and consonants of each syllable with all the other phonemes by a predefined value (*PInRate*). The following table summarizes the model's parameters.

Table 3. Model Parameters

Population	Total number of agents	Default=20
Perc0	Percentage of type0 agents	variable
TotalSteps	total number of simulation cycles = duration of the simulation run	variable
LRate	Amount to add to the contextStrengthof word to be learned (dominant)	Default=0.02
LInRate	Amount to subtract from contextStrength of competitive words (subordinate)	Default=0.01
PRate	Amount to add to the phonologicalStrenth of the phonetic combination to be learned	Default=0.02
PInRate	Amount to subtract from the phonologicalStrength of the competitive phonetic combinations	Default=0.01

3 Simulation

In our simulations the two languages are either created at random, or loaded from a previously saved simulation. There is a standard phonetic alphabet, which is used as base for all the languages created and tested.

3.1 Language creation

First the phonological matrix is randomly initialized with values from 0 to 1. Next, words with syllables whose phonological possibilities exceed the phonological threshold are created randomly. Finally, for each social activity of the simulation, a context is created in the context lexicon which contains all the previously created words associated with randomly initialized contextStrength values. Each word has also a phonologicalStrength, which is the average phonologicalStrength of its syllables.

3.2 Activities creation

The activities are also either created at random, or loaded from a previously saved simulation. An activity is characterized by its type and by the maximum number of participants (*maximumAgents*). The actual number of participants can be lower in cases that an agent cannot be found (in some activities participation is voluntary), but is not allowed to be less than 2.

3.3 Simulation cycle

A simulation uses a newly created or loaded world (languages, activities and agents) and executes for *TotalSteps* times. At each cycle an activity is selected at random, and is randomly assigned a predefined number of agents (up to maximumAgents for the selected activity). Next the number of speakers is randomly initialized with a value between 1 and the actual agents' number. Next an agent is selected at random to be the speaker and the rest of the agents act as listeners. This happens for as many times as the number of speakers.

4 Experiments

A typical experiment consists of several simulations using the same languages and variations of the model parameters. Some parameters though remained fixed across the experiments. Those were the parameters that guided the lexical and phonological learning process (by default LRate=0.02, LInRate=0.01, PRate=0.02, PInRate=0.01) and the thresholds (by default LThresh=0.6, PThresh=0.6). The initial type0 language used in the experiments reported below, is given in the following tables. Unless mentioned otherwise in all the following experiments the rest of the parameters have the values: population=20, perc0=0.2. For figures that shows the evolution in time (simulation cycles) of the contextStrength of the words that was active (contextStrength > LThresh) for some time during the simulation, each word has a suffix which represents its origin (for example 0 for language0).

Table 4. Original context lexicon for language0.

word	activity	phonologicalStrength	contextStrength
zhouix	0	0.797	0.793
iekuix	0	0.797	0.001
awthou	0	0.851	0.002
pexao	0	0.778	0.021
iezon	0	0.682	0.82
zhouix	1	0.797	0.509
iekuix	1	0.797	0.503
awthou	1	0.851	0.491
pexao	1	0.778	0.458
iezon	1	0.682	0.843
zhouix	2	0.797	0.1
iekuix	2	0.797	0.639
awthou	2	0.851	0.158
pexao	2	0.778	0.327
iezon	2	0.682	0.934

Table 5. Original phonological matrix for language0.

	a	ao	o	ou	u	ui	i	ie	e
b	0.57	0.08	0.92	0.5	0.47	0.34	0.62	0.12	0.28
p	0.09	0.76	0.35	0.29	0.22	0.36	0.2	0.02	0.62
f	0.13	0.38	0.19	0.3	0.39	0.53	0.18	0.07	0.19
v	0.82	0.57	0.15	0.28	0.52	0.41	0.48	0.78	0.85
g	0.96	0.22	0.08	0.23	0.63	0.01	0.22	0.92	0.72
c	0.65	0.93	0.4	0.2	0.08	0.35	0.04	0.45	0.35
ch	0.56	0.6	0.75	0.71	0.81	0.79	0.03	0.98	0.56
k	0.43	0.61	0.02	0.33	0.52	0.64	0.31	0.68	0.05
w	0.86	0.51	0.18	0.56	0.37	0.39	0.19	0.33	0.31
x	0.92	0.94	0.7	0.72	0.98	0.92	0.91	0.09	0.61
d	0.22	0.38	0.98	1	0.02	0.52	0.54	0.91	0.43
t	0.88	0.45	0.34	0.65	0.64	0.82	0.21	0.32	0.51
th	0.74	0.56	0.01	0.84	0.85	0.82	0.88	0.74	0.07
thh	0.86	0.4	0.37	0.03	0.9	0.07	0.03	0.33	0.16
r	0.68	0.88	0.44	0.38	0.85	0.89	0.99	0.23	0.41
l	0.11	0.07	0.39	0.07	0.8	0.71	0.22	0.53	0.44
m	0.27	0.47	0.42	0.84	0.17	0.57	0.07	0.13	0.13
n	0.18	0.24	0.63	0.2	0.55	0.63	0.46	0.74	0.58
s	0.57	0.15	0.84	0.86	0.31	0.52	0.73	0.6	0.34
sh	0.72	0.21	0.25	0.49	0.85	0.05	0.74	0.08	0.51
z	0.93	0.23	0.41	0.76	0.14	0.35	0.59	0.73	0.58
zh	0.23	0.44	0.28	0.68	0.26	0.02	0.11	0.6	0.45

We have performed several experiments whose key results are given below:

4.1 Lexicon growth.

The context lexicon of all agents is initially growing, as the words of the different types are exchanged during interactions, and as new words continuously emerge due the differences in the phonology of the two languages. However, only few words become eventually active (their contextStrength exceeds LThresh). Figure 1 shows the average number of the new words that emerged in each activity.

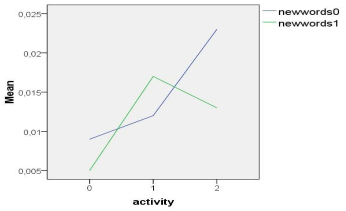


Fig. 1. Average (1000 cycles) number of new words that emerged in the context lexicon of agents type0 and type1, by activities.

4.2. Transformation of phonetics.

The phonological learning leads to modification of the phonological matrices, which practically means that some phonemes eventually vanish from the language and others emerge and stabilize. The following tables give the final average phonological matrix for all agents and the final phonological matrix for a random type0 agent. It is clear that few phoneme combinations increase over time and reach the maximum value of 1. Those are exactly the phoneme combinations included in the words that survived the competition (for example the words for activity2 in Fig 2). Competitive combinations tend to 0, and there are also some combinations unaffected by the learning process. Because of the competition in the phonological matrix, it is possible for a phonetic combination which is initially valid (phonologicalStrength > PThresh), to become extinct. If it is a syllable in a word, this word will no longer be recognizable by its users and it might be replaced by a close one (mutation, see also Fig 2).

Table 6. Phonological matrix for language0 at the end of the simulation (totalSteps=2000). Average of all agents

	a	ao	o	ou	u	Ui	i	ie	e
b	0	0	0	0	0	0,16	0	0	0,14
p	0	0	0	0	0	0,15	0	0	0,59
f	0	0	0	0	0	0,35	0	0	0,05
v	0	0	0	0	0	0,23	0	0	0,74
g	1	0	0	0	0	0	0	0	0
c	0	0	0	0	0	0,17	0	0	0,21
ch	0	0	0	0	0	0,61	0	0	0,42
k	0	0	0	0	0	0,47	0	0	0
w	0	0	0	0	0	0,21	0	0	0,17
x	0	0	0	0	0	0	1	0	0
d	0	0,96	0	0	0	0	0	0	0
t	0	0	0	0	0	0,86	0	0	0,29
th	0	0	0	1	0	0	0	0	0
thh	0	0	0	0	0	0	0	0	0,02
r	0	0	0,09	0	1	0	0	0	0
l	0	0	0	0	0	0,7	0	0	0,21
m	0	0	0	0	0	0,43	0	0	0
n	0	0	0,23	0	0	0	0	0	0
s	0	0	0	0	0	0,31	0	0	0,17
sh	0	0	0	0	0	0	0	0	0,37
z	0	0	0	0	0	0	0	1	0
zh	0	0	0	0,01	0	0	0	0	0

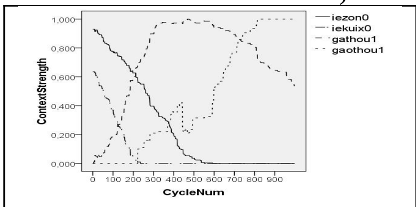
Table 7. Phonological matrix for language0 at the end of the simulation. Random agent

	a	ao	o	ou	u	Ui	i	ie	e
b	0	0	0	0	0	0,18	0	0	0,15
p	0	0	0	0	0	0,19	0	0	0,52
f	0	0	0	0	0	0,37	0	0	0,06
v	0	0	0	0	0	0,24	0	0	0,75
g	1	0,01	0	0	0	0	0	0	0
c	0	0	0	0	0	0,19	0	0	0,22
ch	0	0	0	0	0	0,63	0	0	0,43
k	0	0	0	0	0	0,46	0	0	0
w	0	0	0	0	0	0,22	0	0	0,17
x	0	0	0	0	0	0	1	0	0
d	0	0,84	0	0	0	0	0	0	0
t	0	0	0	0	0	0,84	0	0	0,32
th	0	0	0	1	0	0	0	0	0
thh	0	0	0	0	0	0	0	0	0,03

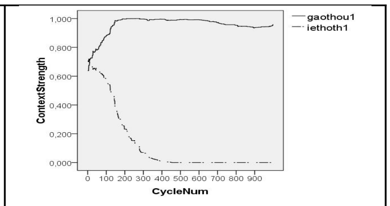
r	0	0	0,17	0	1	0	0	0	0
l	0	0	0	0	0	0,7	0	0	0,18
m	0	0	0	0	0	0,46	0	0	0
n	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0,35	0	0	0,2
sh	0	0	0	0	0	0	0	0	0,38
z	0	0	0	0	0	0	0	1	0
zh	0	0	0	0	0	0	0	0	0

4.3 Linguistic Convergence.

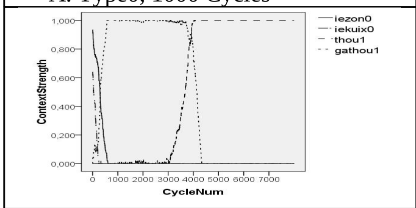
Although in short simulations the dynamics of the languages are rich, for longer runs all simulations converge to a stable state, where all the agents that participated in each specific activity share common words. Because the system is open (there are not objects associated with words), depending on the initial phonologicalStrength, contextStrength, and the interaction frequency, the stable state is not always equivalent. In some simulations the agents end up sharing one common word for all activities, in others they share a common word, which is different for each activity, and there are also simulations, whose agents share two common words for some activity, which are in equilibrium. The following figures show the first 1000 cycles of the simulation run: many words are simultaneously present in the lexicon of both type0 and type1 agents, but some of these die out because of competition and after about 2000 cycles the agents become monolingual, that is all type 0 and type1 agents converge to the same words(s). (All the following data are indicative, taken from a single simulation. In all cases tested the simulations stabilize at some time.)



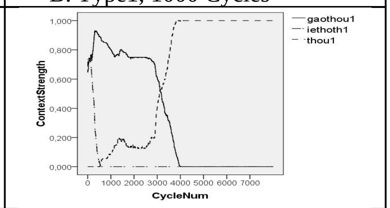
A. Type0, 1000 Cycles



B. Type1, 1000 Cycles



C. Type0, 8000 Cycles



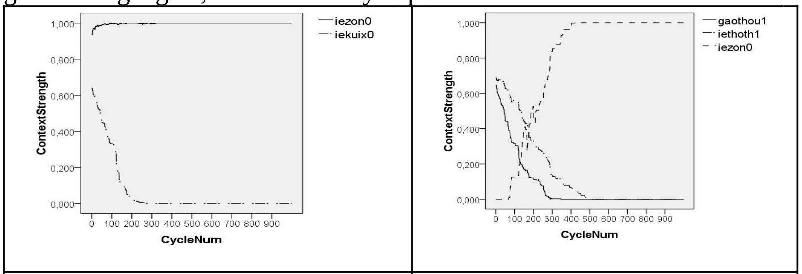
D. Type1, 8000 Cycles

Fig. 2. Average contextStrength for words used by agents type0 (A,C) and type1 (B,D) in activity 2 by number of cycles, for number of cycles=1000 (A,B) and 8000 (C,D), population=20, perc0=0.2. A) The initial words ("iezon", "iekuix") die out and get replaced, initially by the approximation "gathou" of the original type1 word "gaothou", with the latter to be replaced again by the exact type1 word as the phonological matrices of type0 agents gradually converge to type1 phonology. B) The word "gaothou" wins the competition. C) Another execution of the same simulation where the type1 word "gaothou", has been replaced by the word "thou" in type1 agents before becoming active in type0 agents (shown in D). The simulation stabilizes at about 4500 cycles. D) A new mutation ("thou") of the word "gaothou" takes over and wins the competition.

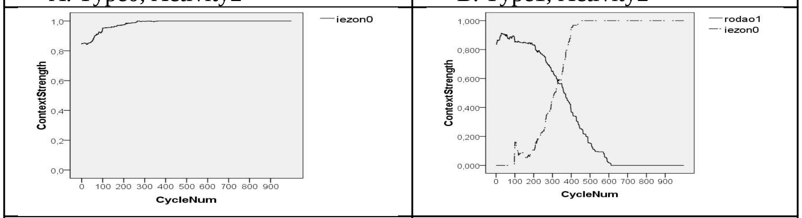
The speed of the convergence depends on the frequency of the interactions as well as on the initial languages' properties (the initial number of competitive words for each activity and the similarity of the initial words), as well as the initial similarity between them.

4.4. Linguistic dominance.

Because agents are randomly assigned in each activity, the frequency of interactions is defined solely by the population composition. In a population with perc0=0.2, all agents will interact approximately four times more with type 1 agents than with type 0 agents. As a consequence, the words of the resulting language will be closer, and in some cases directly copied, from the initial type1 language. The following figures report the results of an experiment with perc0 = 0.8. It is found that the final language for both type 0 and type 1 is derived from language 0, unlike the results of the experiment in section 4.3 where perc0 was 0.2 and the final language was derived from language 1. We have also verified that when perc0 is close to 0.5, i.e. when the initial populations are of about the same size, the resulting language may be closer to either language 0 or language 1, as theoretically expected.



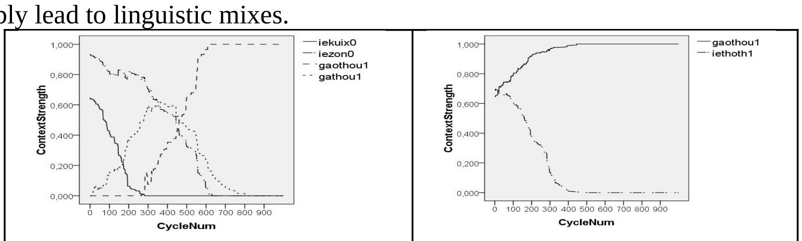
A. Type0, Activity2	B. Type1, Activity2



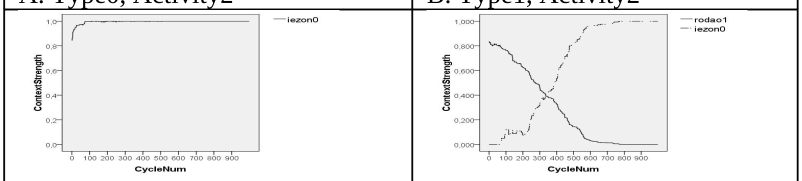
C. Type0, Activity 1	D. Type1, Activity1

Fig. 3. Average contextStrength for words used by agents type0 (A,C) and type1 (B,C) in activity 2 (A,B) and 1 (C,D) by number of cycles, for number of cycles=1000 perc=0.8. Because type0 agents is the majority, their language dominates in both activities. Type1 agents adopt “iezon”, a language0 word (B,D).

Finally, we have run preliminary experiments to further confirm the hypothesis that the actual linguistic outcome is dependent on the relative frequencies of interaction between agent types. If this holds, then in environments with variable interaction schemes for different activities, a linguistic mix may emerge. Indeed, when we introduce a different speaker probability for each agent type in each activity, the resulting language is a mix of words of both origins: see figure 4 below, where, for activity 1, type0 agents are more probable to speak (speakProbability = 0.8) than type1 agents (speakProbability = 0.2). Overall, these results demonstrate that the linguistic outcome depends exclusively on the frequency of interactions between agents of various types; a single global interaction scheme will induce a language of single origin, whereas significant local variations of frequency of interaction will most probably lead to linguistic mixes.



A. Type0, Activity2	B. Type1, Activity2



C. Type0, Activity1	D. Type1, Activity1

Fig. 4. Average ContextStrength for words used by agents type0 (A,C) and type1 (B,D) in activity 2 (A,B) and 1 (C,D) by number of cycles, for number of cycles=1000, and speakProbability= 0.8 for type0 agents and 0.2 for type1 agents, in activity1. In activity 1, the winning word comes from language0 “iezon” (A,B), but in activity 2, the winner comes from language1 “gaothou1” (C,D).

4.5. Intensity of interaction.

In the above experiments, the results show that the crucial parameter which determines the final converged common language is the frequency of interaction, that is dependent directly or indirectly on the relative percentage of the two groups. The activities scenario does not have any other effect and the assumed master-slave relationship is not taken into account explicitly. We would like to understand which other social parameter should be involved in phonological and lexical learning and how, so as to be able to reproduce the usual finding that the final language that dominates in a master-slave environment is usually the master’s language and this independently of the relative size of the two populations or of their interaction structure. We introduce a new parameter, called intensity of the interaction [16], which may be thought of as the amount of attention an agent pays to the speaker during interaction. A more attentive agent is an agent that practically learns faster. Intensity of interaction is implemented as the number of interactions between speaker and listener at each encounter and corresponds to perceptual-processing speed of the linguistic imitation device[1]. With an intensity value relatively high for speakers of type0, and low for speakers of type1, the results obtained are as expected by the master – slave scenario. The following figures show the results for intensity=10 for speakers of type0 and intensity=2 for speakers of type1, in a population of perc0 = 0.2 (four times as many type 1 agents). The control of this parameter may be responsible for the reversal of fate in populations of variable composition.

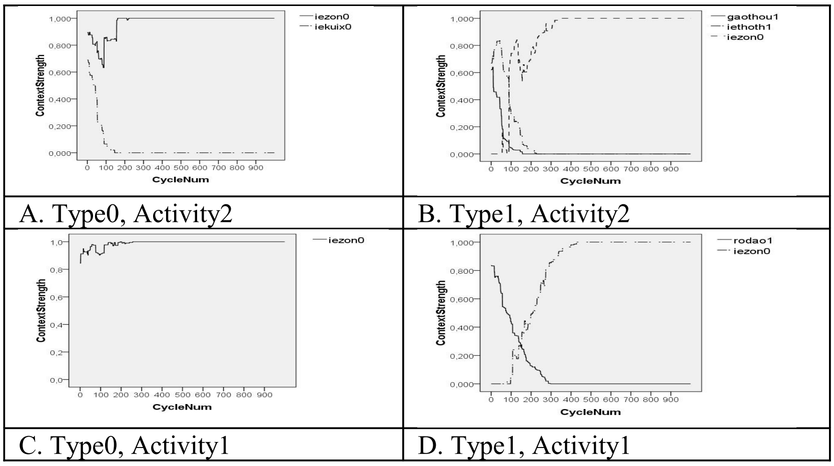


Fig.5. Average contextStrength for words used by agents type0 (A,C) and type1 (B,D) in activity 2 (A,B) and 1 (C,D) by number of cycles, for number of cycles=1000, with intensity=2 for type1 and 10 for type0 agents. Type0 agents dominate linguistically although they are the minority(A,C). Type1 adopt language0 word “iezon” in both activities (B,D).

4.6 Perceptual cost

In the next experiment we introduce a new concept, which is called perceptual cost of the linguistic device, so that when an input syllable is not phonologically recognized, the neighbor with maximum phonological strength is more likely to be selected. This arrangement captures the fact that any unknown syllable found will be prone to be associated with the preexisting syllable that is phonetically closest (thus the one with the minimum relative perceptual cost). Table 8 shows the implementation.

1 Introducing different rates for language 0 learning than for language 1 has been found not to have an effect on the type of language emerged, but only on the speed of convergence. Due to lack of space we omit these results

Table 8. The modified part of the listening algorithm that implements the perceptual cost of the linguistic device.

```
        //loop2

        foreach new_syllable in the four closest vowel-consonant
  combinations //(see tables 6 and 8)

          select the one with max phonological strength with
  probability=variable (cost)

          else select random neighbor

          executePLearning(selected_neighbor)

        exit foreach-loop2
```

The following figure shows the results of the simulation with cost=0.95 for type1 agents, and cost=variable for type0 agents.

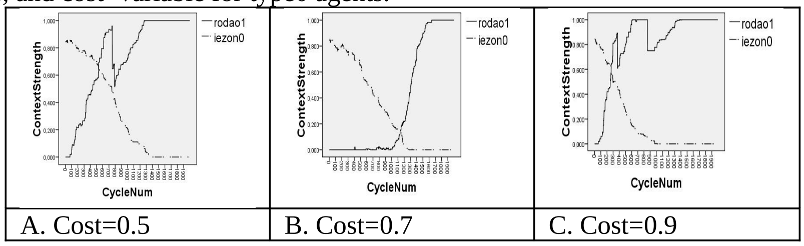


Fig. 6. Average ContextStrength for words used by agents type0 in activity 1 by number of cycles (A,B,C), for number of cycles=2000, and perceptual cost = 0.5, 0.7, 0.9 for type0 agents, perceptual cost=0.95 for type1 agents.

The results show that the final convergence of the system is as before, but the transitive languages may be more volatile than in the original case.

4.7 Linguistic Mix

So far, we have seen that the model stabilizes in monolingual states, whose dominant language depends on the size or intensity of each group. Next we report experiments whose result is a linguistic mix. In the first experiment, linguistic mix is determined by a social factor: the relative size of speakers between the two groups. So type0 agents are more probable to speak (speakProbability=0.8) than type1 agents (speakProbability=0.2) in activity1. Figure 7 shows the results.

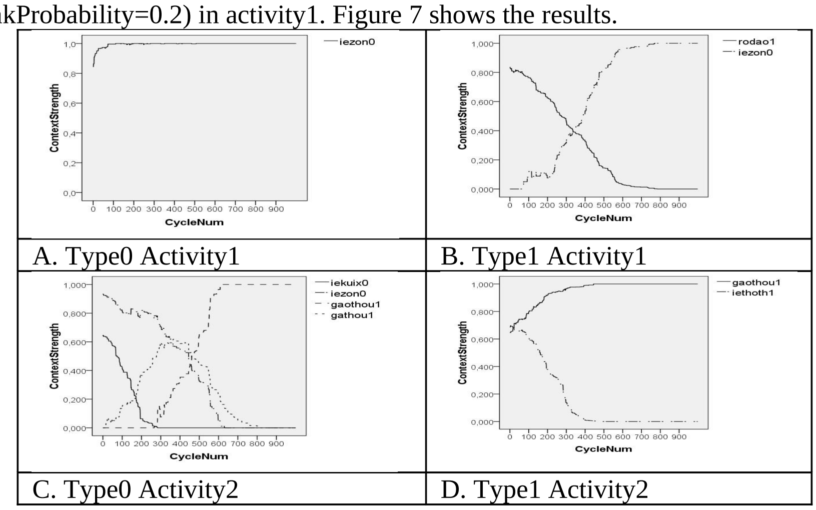


Fig. 7 Average ContextStrength for words used by agents type0 (A,C) and type1 (B,D) in activity 1 (A,B) and 2 (C,D) by number of cycles, for number of cycles=1000, and speakProbability= 0.8 for type0 agents and 0.2 for type1 agents. The winner word for activity 1 comes from language0 “iezon” (A,B), but the winner for activity 2 comes from language1 “gaothou1” (C,D).

In the next experiment linguistic mix is the result of a cognitive factor. We model the situation where each agent has its own intensity value, rather than a value common to all agents of the same type. So, for type0 speakers, listeners have a random intensity value from the uniform distribution in [5,10], and for type1 speakers, listeners have a random intensity value from the uniform distribution [2,5]. The following figure shows the results.

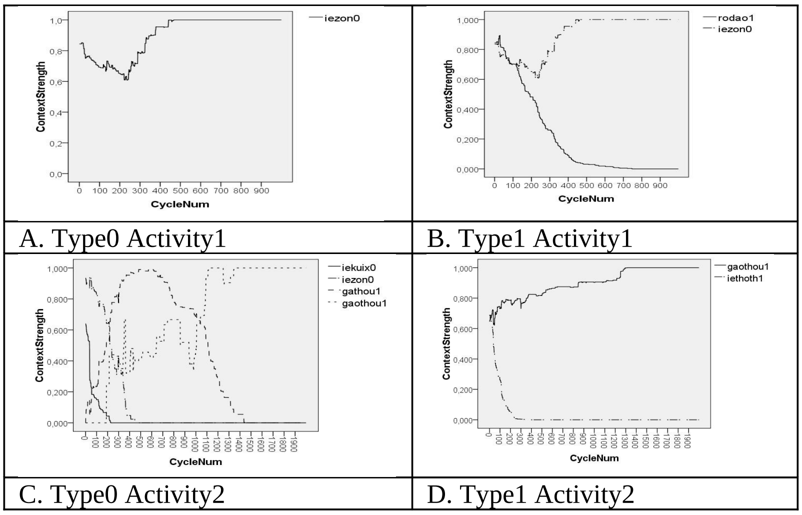


Fig. 8. Average ContextStrength for words used by agents type0 (A,C) and type1 (B,D) in activity 1 (A,B) and 2 (C,D) by number of cycles, for number of cycles=2000, with intensity for type0 speakers random uniform in[5,10] and for type1 speakers random uniform in [2,5], for all listeners. In activity 1 the winner comes from language0 “iezon” (A,B), but in activity 2 the winner comes from language1 “gaothou”(C,D).

As before, the final language contains a mix of lexical items from the initial languages. Once more, we may claim that in any language that appears to be a mix of other or older languages, the dominance of certain words or other linguistic features may be partly attributed to cognitive factors, whereby some people are more attentive toward one language and put conscious effort to learn it. Our results support the known fact that generally people of a lower class or social or educational status are more prone to revert to another language independently of relative population sizes.

5. Conclusions and Further Work

In this paper, we have studied a simple model of combined linguistic change at the phonological and at the lexical level. We have experimented with a population of agents of two distinct linguistic origins that interact with one another through participation in different social activities. It has been shown, that after an initial period where many, unstable, short-lived words emerge, the population stabilizes to a mono-lingual configuration with lexical and phonological resemblance to the language of the bigger group, because relative population size determines the frequency of interactions with the two types of agents. In settings where the structure of interaction is variable across social activities, linguistic mixes may emerge, that comprise words of various origins that happened to dominate in different activities. It has been also shown that an additional intensity of interaction possibility, implemented as amplified attention to the socially dominant group (the “master” in a “master-slave” setting), may account for convergence to a language that resembles more the dominant language, independently of relative size of the two populations. The main innovations of the above model are two: first, the intensity of interaction as defined is independent of the frequency of interaction, showing precisely that some social factors may feed back, constrain and direct the otherwise impulsive linguistic imitation. Moreover, it would not be far-fetched to assume that in some cases an agent might have some limited conscious control over the intensity of interaction, thus for example resisting and suppressing learning or accelerating it within physical limits. Second, the phonological and lexical changes may be themselves independent, for example we could easily assume that agents may resist phonological change but not lexical change, because the latter is absolutely necessary for communication. Inversely, one could imagine that some agents would change phonologically impulsively at a slow pace, but have better control over lexical change.

Immediate extensions of the model include introduction of a “communicative reference”, i.e. objects that have to be named and not just words that are spoken out. We would like to see whether the need for cross-reference in different social contexts has an effect on the final language obtained, if any, for example whether stable language mixes are possible. Experiments with various other social settings are envisaged. A second extension concerns the introduction of arbitrary phonological changes with associated change costs, corresponding to arbitrary but cost-driven linguistic learning (cost is considered by some authors to be the defining parameter for complexity, see for example [6]). These future work aims at gaining more understanding of the factors and processes that generate, influence and maintain linguistic diversity within a population of any origin.

References

1. Perfors A. Simulated Evolution of Language: a Review of the Field, Journal of Artificial Societies and Social Simulation vol. 5, no. 2. 2002
2. Maynard Smith J., Szathmáry E. The major transitions in Evolution, 1. Oxford University Press, USA 1998
3. Oyama S., Gray R.D., Griffiths P. E. Cycles of Contingency: Developmental Systems and Evolution (Life and Mind: Philosophical Issues in Biology and Psychology). The MIT Press. 2003
4. Nolfi S., Mirolli M. Evolution of Communication and Language in Embodied Agents. Springer Heidelberg Dordrecht London New York. 2010
5. Angelo Cangelosi A. Smith A. D. M., Smith K. The Evolution of Language. Proceedings of the 6th International Conference (EVOLANG6). World Scientific Publishing. 2006
6. Miestamo M., Sinnemäki K, Karlsson F. Language Complexity. Typology, contact, change. John Benjamins Publishing Company.Amsterdam / Philadelphia. 2008
7. Sampson G., Gil D., Trudgill P. Language Complexity as an Evolving Variable. Oxford University Press 2009.
8. Dahl O. The Growth andMaintenance of Linguistic Complexity. John Benjamins Publishing Company.Amsterdam / Philadelphia. 2004
9. Dessalles J.L. Why We Talk. The Evolutionary Origins of Language. Oxford University Press, USA. 2007
10. McMahon A. Understanding language change, Cambridge University Press.1994
11. Kouwenberg S. & Singler J.V. The Handbook of Pidgin and Creole Studies. Blackwell Publishing Ltd. 2008.
12. Satterfield T. Back to nature or nurture: Using computer models in creole genesis. In Eckardt R., Jager G., Veenstra T. Variation, Selection, Development. Probing the Evolutionary Model of Language Change. Mouton de Gruyter. Berlin • New York. 2008
13. Beltran et al. Forecasting a Language Shift Based on Cellular Automata Journal of Artificial Societies and Social Simulation 12 (3) 5. 2009
14. Castello X. et al. Modelling bilingualism in language competition: the effects of complex social structure. ESSA 2007
15. Oudeyer P.Y. The self-organization of speech sounds. Journal of Theoretical Biology 233. 435–449. 2005
16. Gumperz J.J. Discourse Strategies (Studies in Interactional Sociolinguistics). Cambridge University Press. 1982