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Description	

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Exposure Dependent Creolization in Language Dynamics Equation

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Abstract. The purpose of this paper is to develop a new formalism of language dynamics so that creole may emerge. Thus far, we modified the *transition probability* of the dynamics so as to change in accordance with the distribution of population of each language at each generation, and in addition, we introduced a new parameter called *exposure rate* with which infants were exposed to other languages than mother tongues. Thus, we could observe creolization under limited conditions. In this paper, we revise the learning algorithm in our model, considering the amount of language input during the language acquisition period. Thus, the transition probability depends not only on the exposure rate but also on the amount of language input. With this model, we show that creolization occurs only when the influence of mother tongues and the socially dominant languages balance.

1 Introduction

In general, children correctly inherit language from their parents and/or neighbors during their acquisition period, even though it has not yet been clarified how children correctly deduce the underlying grammatical rules and acquire the same language as their mothers'. In other cases, some children whose parents speak a pidgin may acquire another new language called a creole. Pidgin and creole are defined as two different stages of language change [1, 2]. Pidgin is a simplified tentative language spoken in multilingual communities. Creole is a full-fledged new language which children of the pidgin speakers obtain as their native language. Some properties of creoles imply the existence of an innate universal grammar.

Linguistic studies are going to have clarified why and how creoles emerged. Observing actual pidgins and creoles, linguists have argued that creoles would appear under a specific environment like a pidgin community [1–3]. From the linguistic efforts, it is clear that the emergence of creole is affected by contact with other languages, the distribution of population of each language and similarities among the languages. In population dynamics [4], by parameterizing these elements, we could derive conditions for the emergence of creole from the theoritical and numerical analyses [5], and then could contribute to specify the function of the universal grammar.

Thus far, we revised the language dynamics by Nowak et al. [6] in such a way that the transition rates changed according to the distribution of population of each grammar at each generation. In addition, we introduced an *exposure rate* which assesses an extent that a child is exposed to other languages than that of his/her parents. Using this approach, we have shown the emergence of a creole when multiple parental languages are similar in some way [7, 8]. We improved our model to exclude *fitness* that dominated the ratio of offsprings with regard to communicability [9]. We observed such unnatural phenomena that the creole emerged even when children learned language only from their parents. In this paper, we will present a new formalism to remedy this problem.

In Section 2, we describe our previous model. In Section 3, we present the new formalism and in Section 4 we define a creole in population dynamics. Section 5 reports our experiments. We conclude in Section 6.

2 Language Dynamics Equation without Fitness

In this section, we breafly explain our previous model and consider the emergence of creole in population dynamics.

In response to the language dynamics equation by Nowak et al. [6], we assume that any language is classified into one of a certain number of grammars. Thus, the population of language speakers are distributed to a finite number (n) of grammars $\{G_1 \ldots G_n\}$. Let x be a ratio of speakers of each language. Then, the language dynamics is modeled by an equation governing the transition of language speakers among languages.

In the language dynamics equations, the similarity matrix S and the transition matrix $\overline{Q}(t)$ play important roles. The similarity matrix $S = \{s_{ij}\}$ denotes the probability that a sentence of G_i is accepted by G_j. The transition matrix $\overline{Q}(t) = \{\overline{q}_{ij}(t)\}$ is defined as the probability that a child of G_i speaker obtains G_j by the exposure to his/her parental language and to other ones. Being different from the definition by Nowak et al., our definition of $\overline{Q}(t)$ depends on the generation parameter t, as well as the S matrix and a learning algorithm.

Because Nowak et al. assume that language speakers bear offsprings in proportion to their successful communication, they embed a fitness term in their model which determines the birth rate of each language group. Our model excludes the fitness on the assumption that in the real world creoles do not emerge because creole speakers have more offsprings than that of other pre-existing languages. We have already shown the difference between the models with and without fitness [9], in which the latter becomes:

$$\frac{dx_j(t)}{dt} = \sum_{i=1}^{n} \overline{q}_{ij}(t)x_i(t) - x_j(t) \ . \tag{1}$$

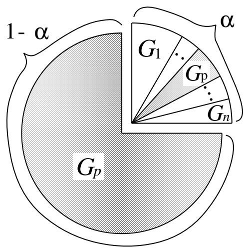


Fig. 1. The exposure rate α

3 Language Acquisition and Transition of Population

In this section, we propose a new transition matrix $\overline{\overline{Q}} = \{\overline{\overline{q}}_{ij}(t)\}$. Our approach takes account of a probability distribution of the number of acceptable sentences for each grammar against the number of input sentences during acquisition term. Firstly, we explain the learning algorithm. Secondly, we represent the transition matrix $\overline{\overline{Q}}$.

3.1 Learning Algorithm

In some community, a child learns language not only from his/her parents but also from other adults, whose language may be different from the parental one. In such a situation, the child is assumed to be exposed to other languages, and thus may acquire the most efficient grammar in accepting those language input. In order to assess how often the child is exposed to other languages, we divide the language input into two categories: one is from his/her parents and the other is from other language speakers. We name the ratio of the latter *exposure rate* α. This α is subdivided into the smaller ratios corresponding to those other languages, where each ratio is in proportion to the population of the language speakers. An example distribution of languages is shown in Fig. 1. The child of G_p speaker is exposed to G_p at the rate of the shaded part, that is $\alpha x_p + (1-\alpha)$, and the ratio of a non-parental language G_i comes to be αx_i.

Our learning algorithm resolves Niyogi [10]'s problem that there is an unrealistic Markov structure which implies that some children cannot learn certain kinds of language. From the viewpoint of a universal grammar that all conceivable grammars of human beings are restricted to a finite set, language learning is considered as a choice of a plausible grammar from them. The following algorithm realizes such learning as: 1) In a child's memory, there supposed to be a score table of grammars. 2) The child receives a sentence uttered by an adult. 3) The acceptability of the sentence is tested for each grammar. The grammar which accepts the sentence scores 1 point. 4) 2) and 3) are repeated until the child receives a fixed number (w) of sentences, that is regarded as enough for the estimation of the grammar. 5) The child adopts the grammar with the highest score.

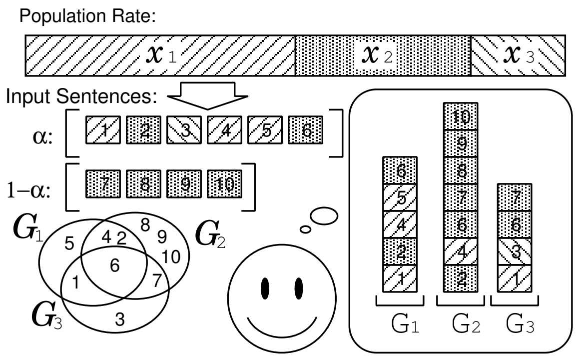


Fig. 2. The learning algorithm

The distribution of population and the exposure rate α determine the rate of adult speakers of each language to which the child is exposed, while the S matrix determines the acceptability of a sentence. In Fig. 2, we show an example where a child of G_2 speaker obtains G_2 after the exposure to a variety of languages. The child receives sentences, that are numbered boxes from 1 to 10. The input sentences are divided into two sets according to the exposure rate α. One of the sets consists of sentences of all grammars. The number of the sentences of each grammar is proportional to the rate of population of the grammar. For example, the child hears sentences 1, 4 and 5 uttered by G_1 speakers. The other consists of sentences of his/her parents. Therefore, these sentences are acceptable by a particular grammar. Because his/her parental grammar is G_2, for example, the sentences 7 to 10 are randomly chosen from the language of G_2. The child counts acceptable sentences for each grammar. The sentence 1 can be accepted by G_3 other than G_1, while it is uttered by a G_1 speaker. The Venn diagram in Fig. 2 represents that each language shares sentences with others. In this case, because the sentence 1 is acceptable both by G_1 and by G_3, the child adds 1 to both of the counters in his/her mind.

3.2 Revised Transition Probability

Suppose that children hear sentences from adult speakers depending on the exposure rate and on the distribution of population. A probability that a child whose parents speak G_i accepts a sentence by G_j is expressed by:

$$U_{ij} = \alpha \sum_{k=1}^{n} s_{kj} x_k + (1-\alpha) s_{ij} \ . \tag{2}$$

After receiving a sufficient number of sentences for language acquisition, the child will adopt the most plausible grammar that is estimated by counting a number of accepted sentences by each grammar. This learning algorithm is simply represented in the following equation. Exposed to a variety of languages in proportion to the ratio of adult speakers, children whose parents speak G_i will adopt G_{j^*} in the following manner:

$$j^* = \underset{j}{\text{argmax}}\{U_{ij}\} \ . \tag{3}$$

When the children hear w sentences, a probability that a child of G_i speaker accepts r sentences with G_j is given by a binomial distribution,

$$g_{ij}(r) = \binom{w}{r}(U_{ij})^r(1-U_{ij})^{w-r} \ . \tag{4}$$

On the other hand, a probability that the child accepts less than r sentences with G_j is

$$h_{ij}(r) = \sum_{k=0}^{r-1}\binom{w}{k}(U_{ij})^k(1-U_{ij})^{w-k} \ . \tag{5}$$

From these two probability distributions, the probability that a child of G_i speaker accepts k sentences with G_j, while less than $k-1$ sentences with the other grammars, comes to $g_{ij}(k)\prod_{l=1,l\neq j}^{n} h_{il}(k)$. For a child of G_i speaker to acquire G_j after hearing w sentences, G_j must be the most efficient grammar among n grammars; viz., G_j must accept at least $\lceil \frac{w}{n} \rceil$ sentences. Thus, the probability $\overline{\overline{q}}_{ij}$ becomes the sum of the probabilities that G_j accepts $w, w-1, \cdots, \lceil \frac{w}{n} \rceil$ sentences. Because each of the sentences is uttered by a speaker and is accepted by at least one grammar, there must be a grammar which accept $\lceil \frac{w}{n} \rceil$ or more out of w sentences. Thus, if G_j accepts less than $\lceil \frac{w}{n} \rceil$ sentences, the child does not acquire G_j. Therefore, $\overline{\overline{q}}_{ij}$ becomes:

$$\overline{\overline{q}}_{ij}(t) = \frac{\displaystyle\sum_{k=\lceil \frac{w}{n} \rceil}^{w}\left\{g_{ij}(k)\prod_{\substack{l=1\\ l\neq j}}^{n} h_{il}(k) + R(k)\right\}}{\displaystyle\sum_{m=1}^{n}\left[\sum_{k=\lceil \frac{w}{n} \rceil}^{w}\left\{g_{im}(k)\prod_{\substack{l=1\\ l\neq m}}^{n} h_{il}(k) + R(k)\right\}\right]} \ , \tag{6}$$

where $R(k)$ is the sum total of the probabilities that the child choose G_j when one or more other grammars accept the same number of sentences as G_j. When there are m candidate grammars including G_j, the probability becomes the one divided by m.

4 Creole in Population Dynamics

Creole is considered as a new language. From the viewpoint of population dynamics, we define a creole as a transition of population of language speakers. Creole is a language which no one spoke in the initial state but most of people come to speak at a stable generation. Therefore, a creole is expressed to such a grammar G_c that: $x_c(0) = 0, x_c(t) > \theta_c$, where $x_c(t)$ denotes the rate of the population of G_c at a convergent time t, and θ_c is a certain threshold to be regarded as a dominant language. In this paper, we set $\theta_c = 0.9$ through the experiments.

We have mainly observed the behavior of the model of three grammars. Suppose the size of language is the same and each sentence of the language is chosen with a uniform probability, the similarity matrix can be expressed as such a symmetric matrix that:

$$S = \begin{pmatrix} 1 & a & b \\ a & 1 & c \\ b & c & 1 \end{pmatrix} . \tag{7}$$

Here, we regard G_3 as a creole grammar, giving the initial condition as $(x_1(0), x_2(0), x_3(0)) = (0.5, 0.5, 0)$. Therefore, the element a denotes the similarity between two pre-existing languages, and b and c are the similarities between G_1 and the creole, and between G_2 and the creole, respectively.

5 Experiments

In this section, we show the experimental result of our model. We examine the conditions that creole appears and comes to be dominant in combinations of the S matrix and α.

5.1 Emergence of Creole

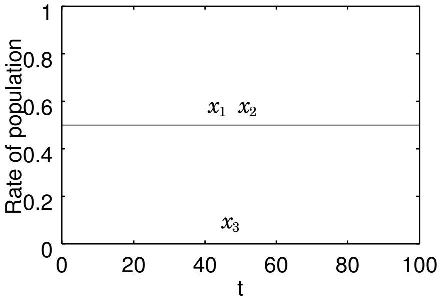
In Fig. 3, we show the result of our model. We arbitrarily set the S matrix to $(a, b, c) = (0, 0.45, 0.35)$, in which the pre-existing grammars G_1 and G_2 do not share any sentence. We gave the number of input sentences $w = 30$ that was found to be large enough for language acquisition in three grammars. The exposure rate α is examined at the range from 0 to 1.

In case $\alpha = 0$, children learn a language only from their parents. Accordingly, Fig. 3(a) shows that both populations of G_1 and G_2 hardly transmit. In the previous model [9], we found a problem that a creole coexists with other languages at $\alpha = 0$. However, we come to resolve the problem.

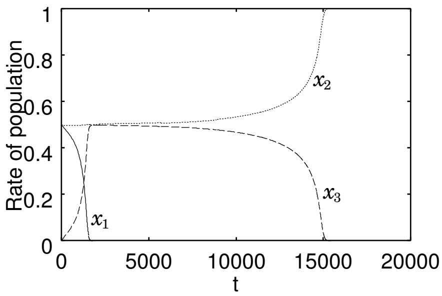
According to the increase of α, x_3 rises gradually though $x_3(0) = 0$, while x_1 falls down to 0 in Fig. 3(b). However, x_3 declined in further generations and eventually disappeared. Because the transition of population depends on Eqn 2, we can approximately compare the directions of transition of population among grammars with Eqn 2. Eqn 8 expresses an expansion of Eqn 2 at $a = 0$.

$$U = \begin{pmatrix} (1-\alpha) + \alpha(x_1 + bx_3) & \alpha(x_2 + cx_3) & (1-\alpha)b + \alpha(bx_1 + cx_2 + x_3) \\ \alpha(x_1 + bx_3) & (1-\alpha) + \alpha(x_2 + cx_3) & (1-\alpha)c + \alpha(bx_1 + cx_2 + x_3) \\ (1-\alpha)b + \alpha(x_1 + bx_3) & (1-\alpha)c + \alpha(x_2 + cx_3) & (1-\alpha) + \alpha(bx_1 + cx_2 + x_3) \end{pmatrix} \tag{8}$$

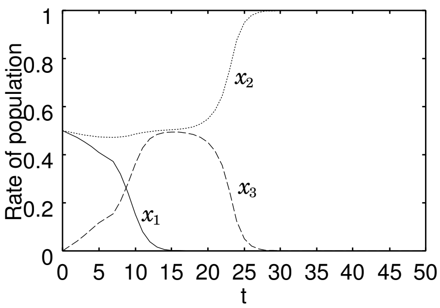
Although the population is shared among only G_1 and G_2 at the initial generation, the increase of α makes the transition from G_1 and G_2 to G_3 active.



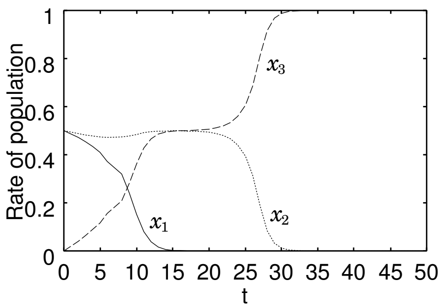
(a) G_1 and G_2 coexist at $\alpha = 0$.



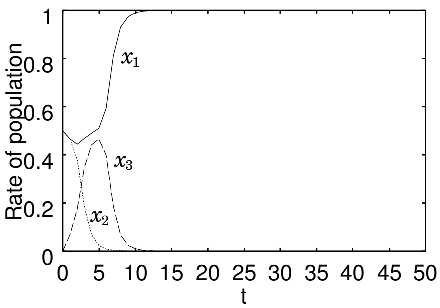
(b) G_2 is dominant at $\alpha = 0.3$.



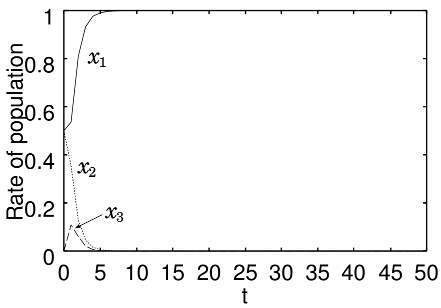
(c) G_2 is dominant at $\alpha = 0.667$.



(d) G_3 is dominant at $\alpha = 0.668$.

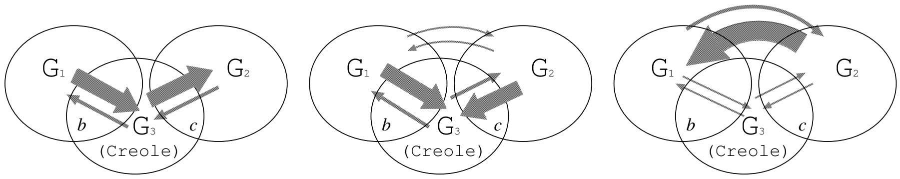


(e) G_1 is dominant at $\alpha = 0.835$.



(f) G_3 is dominant at $\alpha = 1$.

Fig. 3. The transition of dominant language by changing α ($(a, b, c) = (0, 0.45, 0.35)$).



(a) G_2 becomes dominant ($0 < \alpha \leq 0.667$).

(b) G_3 becomes creole ($0.668 \leq \alpha \leq 0.834$).

(c) G_1 becomes dominant ($0.835 \leq \alpha \leq 1$).

Fig. 4. Flow of the population by changing α value ($(a, b, c) = (0, 0.45, 0.35)$)

Because $x_3 \simeq 0$ and $U_{13}, U_{23} > 0$ at early generations, x_1 and x_2 start flowing into x_3. Moreover, because $U_{13} > U_{23}$, x_1 is easier to flow into x_3 than x_2. Once x_3 has earned a certain rate of population, U_{13} becomes greater than U_{31} and the outflow of x_1 to x_3 accelerates, while $U_{23} \simeq U_{32}$. After x_1 mostly diminished, the difference between U_{23} and U_{32} is expanded as the difference between (cx_2+x_3) and (x_2+cx_3), that is x_3 and x_2. Therefore, the difference between the two population rates determines which of the corresponding languages becomes dominant. In case $\alpha = 0.667$ (See Fig. 3(c)), because x_2 is barely more than x_3 at a point of generation at which x_1 mostly disappeared, G_2 finally dominates the community. These flows of the population is shown in Fig. 4(a). We can see that the larger α, the solution converges at the earlier generations in Fig. 3(b) and Fig. 3(c). On the contrary, we have encountered that the solution did not converge in realistic time at a small α.

In case of $(cx_2+x_3) > (x_2+cx_3)$ at the point at which x_1 mostly disappeared, x_3 rises to 1, that is, G_3 becomes dominant at $\alpha = 0.668$. This is the emergence of creole, as shown in Fig. 3(d). Similarly, Fig. 4(b) depicts the process of creolization that in addition to the inflow of population of G_1 the transition from G_2 to G_3 outstrips the outflow of population of G_3.

Further increasing α, we can observe G_1 becomes dominant although it loses the population at the very first in small α. Also, let us pay attention to U_{12} and U_{21} in Eqn 8. At the early generation, x_3 has not earned enough population yet. When α is large enough like Fig. 3(e), U_{12} is larger than U_{13}. Large α represents that children of G_1 speakers grow up, hearing sentences of G_2 in the almost same rate as those of G_1. Therefore, the direct transition between G_1 and G_2 occurs at large α. We show the flows of the population between G_1 and G_2 in Fig. 4(c). Thus, we can regard our experimental result is that creoles are not the easiest to emerge at $\alpha = 1$. This result adequately remedied our fallacious expectation [7].

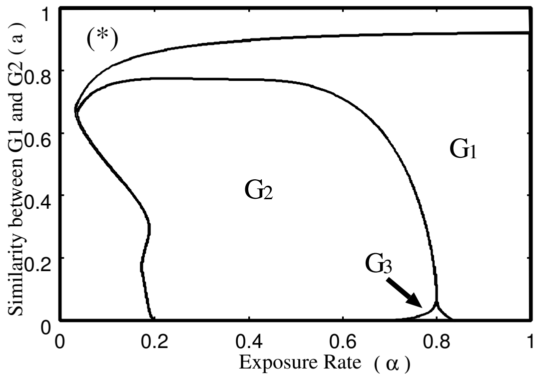


Fig. 5. Distribution of dominant grammars ($(a, b, c) = (a, 0.45, 0.35)$)

5.2 Dominant Language and Creole

In the previous section, we showed the emergence of a creole, and quantitatively considered the process of creolization. We observed that a creole appears within a certain area of α which must be large enough but less than the value at which the direct transition between pre-existing languages becomes mainstream. The value of a in Eqn 7 concerns the direct transition, while it is fixed to 0 in the previous experiment. The next experiment aims at drawing a diagram as to which language would be dominant in various values of the similarity between the pre-existing languages.

By parameterizing a in Eqn 7 and α, we examined the dominant grammar at the convergent generation. The parameter region in which each grammar dominates is shown in Fig. 5. In the figure, the region of asterisk $(*)$ denotes none of the languages becomes dominant. Namely, either the solution converged to the coexistence of a few languages, or the solution could not converge at over a million generations. As we mentioned in the previous experiment, with small values of α the solution hardly converges. On the contrary, in the upper side of the asterisk region, the pre-existing languages coexist because those languages are regarded as an almost identical language at very high value of a.

The previous experiment was examined along with the horizontal axis at $a = 0$. At the bottom of the figure around $\alpha = 0.8$, G_3 (creole) becomes dominant. Thus, the lower value of a, the easier the creole emerges. In other words, a similarity between pre-existing languages implies the ease of surviving of the languages. This result is consistent with that of our previous model [7] that a creole may emerge if the pre-existing languages are not similar to each other, but to the newly appeared language.

6 Conclusion

In this study, we proposed the modified Q matrix of the language dynamics equation [6], where children may migrate to non-parental languages, estimating the number of sentences of probable grammars. In our previous work, we had a problem that children happened to acquire a new language (creole) even when language was given only by their parents [9]. It seems that this unsatisfactory situation was caused by the fact that the learning algorithm could not adjust the amount of language input. We introduced a new parameter concerning this adjustment and examined the behavior on how children guess plausible grammars. As a result, we could show that creolization rarely occurred in high values of the exposure rate α, no less in low values. In a high value of α, children tended to select a pre-existing dominant language, and in a low value they certainly learned parental language; thus, we could contend that creole might emerge between the influence of mother tongues and that of the socially dominant language.

In our future study, we will examine the relation between the amount of language input and the creolization. The preliminary examination showed that the fewer the language input, the easier the creolization occurred. In addition, we need to consider refining the learning algorithm and need to establish a more reliable theory on language similarity.

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