Self Re-organizing of Language triggered by "Language Contact"

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Abstract

Language is a type of communication protocol that emerges and develops through a *self-organizing* process in a multi-agent environment. In this paper, using a *language game* model, we observe and discuss such dynamic properties of languages among communicative agents. We regard language simply as combinations of "words" (symbols) and "meanings" (semantics), namely vocabularies. In addition to preliminary experiments which demonstrate the processes of language emergence and development, we observe experimentally the phenomena caused by *language contact*, where different languages that have been developed separately among distinct groups of agents are brought into contact with each other. Our investigation into these phenomena shows the following results: (1) the language of a majority group tends to be dominant, (2) "language borrowing" may occur when agents need to refer to meanings that have not been familiar to them, (3) languages with incoherence or ambiguity tend to be more distinct through the "*self re-organizing*" processes triggered by the language contact.

1 Introduction

Language is a type of protocol through which agents in a multi-agent system communicate with one another; typical examples of such systems are animal or human societies. However, the "protocols" used in such systems are very different from those, for example, designed for computer networking, because the former possess such complex properties as fluidity, diversity, openness, adaptiveness, and so on, while the latter are static.

In any study of languages, we should not overlook such factors as the emergence, development, and evolution of communication itself. McLennan [3], and Werner and Dyer [10], have conducted experiments on the origins and evolution of communication using the "artificial life" approach. These experiments show that the complexity of a language formed through communication reflects the complexity of the external environment that the artificial organisms inhabit. However, the models used in these studies were not fully adequate for the study of human language, since those formed in the models lack some important characteristics of natural language. In particular, they are closed rather than open systems, and static within each individual of the model society, whereas natural language clearly evolves within each human lifetime [6].

After all, as indicated by the saying "*Language leaves no bones*" [1], there is little direct evidence or empirical knowledge to support investigations into the origin and evolution of language and communication. Moreover, these processes involve various biological and sociological phenomena. Therefore, there are considerable difficulties for research that regards the evolution of language as a by-product of the evolution of individuals who use the language.

On the other hand, another approach can be suggested to explain the diversity and complexity of language, by regarding the language itself as a highly autonomous system with its own peculiar dynamics, by which language evolves even without a complex space or information[2]. In this case, the "system" we consider is an organization with certain properties or functions that emerge from local interactions among multiple constituent elements, although each of the elements itself has no internal mechanisms for such emergent properties. In other words, this approach regards language as an emergent phenomenon that arises and develops through a "*self-organizing*" process [5, 8, 6].

As a result, our language is not as rigid as those for networking or programming computers; but it undergoes constant changes and contains a certain amount of ambiguity. Regardless of these complexities in our language, however, we can still communicate with other members of our species. If anything, we make positive use of this fluidity and diversity for better communication.

In the present paper, in addition to preliminary experiments that demonstrate processes of language emer-

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gence and development, we observe experimentally the phenomenon called *language contact* that occurs when different languages, developed separately among distinct groups of agents, are brought into contact. Such contact can also occur in real languages because of their natural characteristics as open systems, and this process might be a source of the complex properties of language such as fluidity, diversity, adaptiveness, etc.

This paper is organized as follows. The language formation mechanism is introduced in detail in the next §2. The experimental results on the language formation process and language adaptation toward contact are illustrated in §3 and §4, respectively. Some conclusions are given in §5.

2 Language Formation Mechanisms

In this paper, we regard language simply as combinations of "words" and "meanings", namely vocabularies. Meanings take the form of objects. We adopt a *language game* model to form a language among agents. The model used here is a simplified one, which was firstly proposed by Steels [7]. The language formed on this model is open and adaptive in a sense that it may continue to function well even if new agents and new unknown objects are added [7]. Furthermore, we investigate the consequences of contact between the different languages of distinct groups of agents.

2.1 Modelling

We define a set of communicative agents $A = \{a_1, ..., a_m\}$ and a set of objects $O = \{o_1, ..., o_n\}$. A *word* w is expressed as a consonant-vowel sequence, such as "sa" or "ki". An *expression* is a word which is adopted in conversation. Each agent $a \in A$ has its own *lexicon* which is initially empty. A lexicon $L \subset O \times W$ is a relation between an object $o \in O$ and a word $w \in W$. Each member of this relation is called an *association*. The number of times the association $\langle o, w\rangle \in L_a$ is used by a is referred to as $u(\langle o, w\rangle, a)$. Similarly, $s(\langle o, w\rangle, a)$ is the number of times the association $\langle o, w\rangle \in L_a$ is used successfully in a language game (defined shortly) by a. Each association has a score defined as $m(\langle o, w\rangle, a) = s(\langle o, w\rangle, a)/u(\langle o, w\rangle, a)$.

2.2 Language game

A *language game* $g = \langle C, i, r, o\rangle$ consists of a context $C = \{o_j, ..., o_k\} \subseteq O$, an initiator $i \in A$, a recipient $r \in A$, and a topic $o \in C$. The flow of a language game is formed as follows:

1. The initiator i chooses an object o as a topic from the context C.
2. The initiator looks up any words indicating the topic from his/her lexicon, and *speaks* it to the recipient with expression e.
3. On *hearing* the expression e, the recipient now looks up the object indicated from its own lexicon and *guesses* objects on the topic as H.
4. In the case that the context includes an object expected by the recipient, this language game g is considered as a success.

The functions of speaking and hearing are formally defined respectively as follows:

- In the case that an agent $a \in A$ is given as an initiator,

$$speak(o, L_a) = \{e | e = \{w | \langle o, w\rangle \in L_a\}\}.$$

- In the case that an agent $a \in A$ is given as a recipient,

$$hear(e, L_a) = \{H | H = \{o | \langle o, e\rangle \in L_a\}\}.$$

When the initiator tries to speak, it settles on expression e by choosing one word from its lexicon according to probabilities proportional to their association scores. A Boltzmann distribution is used to determine this probability, as follows:

$$p = \exp((m(\langle o, w\rangle, a) - 1)/T)$$

Here, we set the temperature value as T to 0.01.

The additional rules that agents follow in the adoption or formation of language are as follows:

- *In the case of the initiator's lexicon being inadequate*: when the initiator's lexicon does not have any word (association) to express the topic, the language game has failed but there is a certain probability that the initiator creates a new word. In the present experiment, this probability is set to 0.10. This word will be associated with the topic and be added into the lexicon as a new association.
- *In the case of the recipient's lexicon being inadequate*: when the recipient has no words in its lexicon that correspond to expression e, the language game ends in failure, but the expression is associated with objects in context and added into the lexicon as new associations.
- *In the case of both the initiator and the recipient having adequate associations*: according to the H of the set of objects expected by a recipient on hearing e, the results of the game are categorized into the following three cases:
  - *Success*: In the case that objects guessed by the recipient exist in context, the game is a success. $s(\langle o, w\rangle, a)$ and $u(\langle o, w\rangle, a)$ of both initiator and

recipient are incremented by unity. Necessarily, the score $m(\langle o, w\rangle, a)(= s/u)$ of the associations increase, and the associations will get preferably chosen.

- *Mismatch in meaning*: In the case that objects expected by a recipient do not exist in context, the game is failed. Only the implied association $u(\langle o, w\rangle, a)$ of both initiator and recipient are incremented by unity. The score m of the associations decrease, and the associations will get unpreferably chosen accordingly.
- *Partially Success*: When there are several objects expected by the recipient, only some of which exist in context, both $s(\langle o, w\rangle, a)$ and $u(\langle o, w\rangle, a)$ of association regarding objects in context is incremented by unity;but for other associations, only $u(\langle o, w\rangle, a)$ is incremented.

3 Language Formation Process

In this section, we show that agents may develop common vocabularies by mutual interaction through repeated language games.

3.1 Dialogue between agents

A single language game is printed out as follows:

```
Dialogue 102 between a1 and a0 about o4
  context: { o4 o5 o9 }
topic: o4
initiator a1: o4 => li
recipient a0:  o9
```

This shows the 102nd dialogue in a series of language games. In this case, initiator a_2 picks o_4 as a topic from context $\{o_4, o_5, o_9\}$ and expresses it as "li". This expression is guessed as o_9 by recipient a_0. Although o_9 differs from the topic o_4, it does exist in context, so the language game ends in success.

Other examples of language game are shown below.

```
Dialogue 113 between a4 and a3 about o8
  context: { o2 o8 }
topic: o8
initiator a4: o8 => ba
recipient a3: o7
```

In this example, the initiator chooses o_8 as a topic and expresses it as "ba". Recipient guesses this expression as o_7 . However, o_7 does not exist in context, and thus the language game ends in failure.

```
Dialogue 1267 between a2 and a3 about o3
  context: { o3 o7 }
topic: o3
initiator a2: o3 => go
recipient a3:  o3 o1 o0
```

This example shows that a_3 guessed an expression "go " to express o_3, o_1, o_0 . In this case, o_3 exists in the context so the game ends in success. Note that for the effectively relevant association $\langle o_3, go\rangle \in L_{a2}, L_{a3}$, both $s(\langle o_3, go\rangle, a)$ and $u(\langle o_3, go\rangle, a)$ are incremented by unity; but for other associations, only $u(\langle o_i, go\rangle, a)$ (where $i = 0, 1$) is incremented.

```
Dialogue 7 between a0 and a4 about o1
  context: { o2 o4 o1 }
topic: o1
initiator a0: o1 =>
recipient a4:
```

When the initiator has no associations that correspond to the topic, the initiator may create a new word with a certain probability (which is 0.10 in the present experiments) and associate it in his/her lexicon with the topic. In this example, a_0 does not have words that correspond to the topic o_1 in his/her lexicon. Further investigation has revealed that a_0 created a word "no" and associated it in his/her lexicon with the o_1. The game ends in failure.

```
Dialogue 110 between a2 and a1 about o2
  context: { o5 o0 o2 }
topic: o2
initiator a2: o2 => da
recipient a1:
```

When the recipient has no associations that correspond to the expression, the recipient associates it in his/her lexicon with the all objects in the context. In this case, a_1 does not yet have any association which includes the word "da". Thus, a_1 associates "da" with o_5, o_0, o_2 and enters these associations in his/her lexicon. The game ends in failure.

3.2 Language formation

The language formed by iteration among agents of the language game, described in the previous section, is represented in Figure 1.

The horizontal axis of Figure 1 plots the number of language games, while the vertical axis shows the average communicative success (average of every 20th game only). This experiment involved 5 agents and 10 objects.

The communicative success climbs steadily from 0 to become absolute. At first, the communicative success is low because there are few associations in each lexicon, and because words do not have consistent meaning. However, once a word has a consistent meaning, the set of possible choices for the others is reduced. This effectiveness composes a positive feedback mechanism between the selection of a word and the success in using that word, and consequently we see a rapid evolution towards coherence.

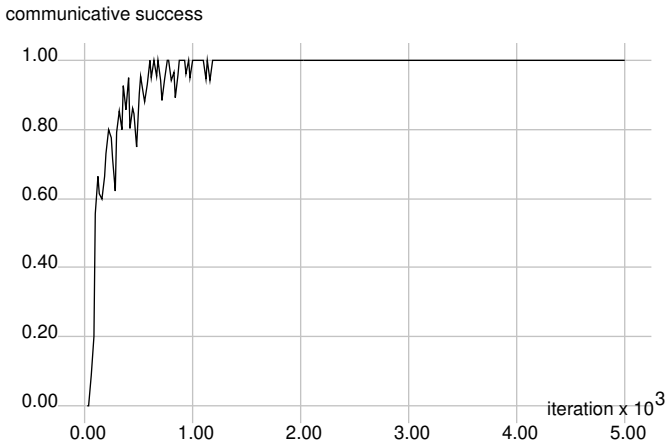

Figure 1: Formation of a language from scratch.

```
obj: word: agent:
o0   (ba)  [ a0 a1 a2 a3 a4 ]
o1   (si)  [ a0 a1 a2 a3 ]
     (qo)  [ a4 ]
o2   (se)  [ a0 ]
     (yo)  [ a1 a2 a3 a4 ]
o3   (go)  [ a0 a1 a2 a3 a4 ]
o4   (du)  [ a0 a1 a2 a3 a4 ]
o5   (nu)  [ a0 a1 a2 a3 a4 ]
o6   (ka)  [ a0 a1 a2 a3 a4 ]
o7   (we)  [ a0 a1 a2 a3 ]
     (qo)  [ a4 ]
o8   (wi)  [ a0 a1 a2 a3 a4 ]
o9   (te)  [ a0 a1 a2 a3 a4 ]
```

Figure 2: The appearance of language formed among agents

Figure 2 shows the language that agents use preferentially (i.e. the word-meaning association with the highest score) after 5000 iterations of the language game.

It is evident from the figure that the language formed in this experiment has a certain amount of both incoherence (for $o1, o2, o7$ two words are used by the agents) and ambiguity ("qo" can mean both o_1 and o_7). These incoherences and ambiguities, however, do not restrict communicative success because agents possess more words than the ones they prefer to use, and therefore can often understand the words of others even if they would not use these themselves.

4 Language Contact

We have shown a process for the emergence of common vocabularies through the language game in the previous section. As noted before, [7] describes how language formed in such a manner may adapt even if new agents and new objects are added.

In this section, we investigate how languages adapt when two different languages, formed through different series of games, are brought into contact.

4.1 Contact of language having the same objects

In two independent worlds (games), the appearance of languages formed among respective agent groups are shown in Figure 3. In each world there are 5 agents, 5 objects, and the game has been iterated 5000 times. The same objects $o_0 \sim o_4$ appear in both games.

Figure 4 shows the language formed among agents after 5000 iterations of the language game since the worlds have come into contact (the adaptation process is shown in Figure 5). In this case, we have selected a_0, a_1, a_2, a_3, a_4 from LANGUAGE_GAME_1 (hereinafter referred to as LG1) and a_5 from LANGUAGE_GAME_2 (hereinafter referred to as LG2) to make contact, so that major and minor groups of agents exist.

In this case, we note the following tendency:

- Language formed among the major group tends to be used after contact.

In fact, as is shown in Figure 4, the minority agent a_5 has come to use words which were used in major group ($a_0 \sim a_4$) to refer to $o_0 \sim o_4$.

However, this tendency becomes vague as the majority becomes smaller.

4.2 Contact of languages having different objects

In the previous section, we illustrated a contact between languages having the same set of objects. In this section,

```
      --LANGUAGE_GAME_1--                    --LANGUAGE_GAME_2--
obj: word: agent:                      obj: word: agent:
o0   (li)  [ a0 a1 a2 a3 a4 ]          o0   (xo)  [ a5 a6 a7 a8 a9 ]
o1   (yu)  [ a0 a1 a2 a3 a4 ]          o1   (ka)  [ a5 a6 a7 a8 a9 ]
o2   (pi)  [ a0 a1 a2 a3 a4 ]          o2   (si)  [ a5 a6 a7 a8 a9 ]
o3   (do)  [ a0 a1 a2 a3 a4 ]          o3   (ge)  [ a5 a6 a7 a8 a9 ]
o4   (vi)  [ a0 a1 a2 a3 a4 ]          o4   (qe)  [ a5 a6 a7 a8 a9 ]
```

Figure 3: The appearance of languages formed through different series of games. Each language contains the same objects.

```
obj: word: agent:
o0   (li)  [ a0 a1 a2 a3 a4 a5 ]
o1   (yu)  [ a0 a1 a2 a3 a4 a5 ]
o2   (pi)  [ a0 a2 a3 a4 a5 ]
     (si)  [ a1 ]
o3   (do)  [ a0 a1 a2 a3 a5 ]
     (ka)  [ a4 ]
o4   (vi)  [ a0 a1 a2 a3 a4 a5 ]
```

Figure 4: Language formed through contact of two languages containing the same objects.

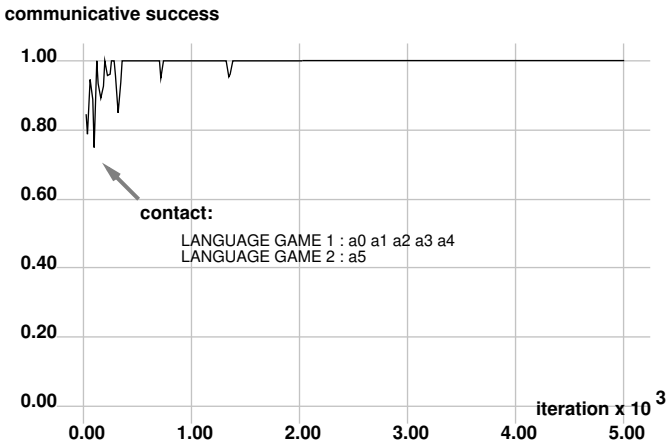

Figure 5: Adaptation of language after contact.

we investigate how the contacting languages adapt when they initially contain different objects.

Figure 6 shows the appearance of languages formed among groups of agents in two independent worlds (games). LANGUAGE_GAME_1 (hereinafter referred to as LG1) contains $o_0 \sim o_4$, while LANGUAGE_GAME_2 (hereinafter referred to as LG2) contains $o_5 \sim o_9$. Note that the objects contained on one side do not exist on the other side.

Figure 7 shows the language formed among agents after 5000 iterations of the language game since contact (the adaptation process is shown in Figure 8). In this case we have selected $a_0 \sim a_4$ from LG1 and $a_5 \sim a_9$ from LG2. Here, we can see the following tendency:

- Language borrowing may occur when the agents refer to objects that had not existed in their language before contact.

Actually, Figure 7 suggests that the words used in LG1 have come to be used for $o_0 \sim o_4$, and the words used in LG2 have come to be used for $o_5 \sim o_9$ after contact, namely the agents have borrowed words directly from the other group.

However, this tendency differs slightly from the one described above when there is a large majority and a correspondingly small minority. Figure 9 shows a language formed among agents after 5000 iterations of the language game since contact (the adaptation process is shown in Figure 10). $a_0 \sim a_4$ of LG1 and a_5 of LG2 are contacted here. This figure shows that while a word for o_6 is borrowed directly, and words for o_7 and o_8 are borrowed indirectly, new words "ce" and "qu" have been created for o_5, o_9, respectively.

These results suggest that when there is a high disparity of majority and minority groups, language does not adapt simply by borrowing but rather by the tendency described below:

- Language borrowing may occur directly or indirectly to refer to objects that had not previously existed in one language.
- New words may be created to refer to objects that had not previously existed in one language.

```
      --LANGUAGE_GAME_1--                    --LANGUAGE_GAME_2--
obj: word: agent:                      obj: word: agent:
o0   (li)  [ a0 a1 a2 a3 a4 ]          o5   (yi)  [ a5 a6 a7 a8 a9 ]
o1   (yu)  [ a0 a1 a2 a3 a4 ]          o6   (fa)  [ a5 a6 a7 a8 a9 ]
o2   (pi)  [ a0 a1 a2 a3 a4 ]          o7   (se)  [ a5 a6 a7 a8 a9 ]
o3   (do)  [ a0 a1 a2 a3 a4 ]          o8   (va)  [ a5 a6 a7 a8 a9 ]
o4   (vi)  [ a0 a1 a2 a3 a4 ]          o9   (su)  [ a5 a6 a7 a8 a9 ]
```

Figure 6: The appearance of languages formed through different series of games. Each language contains different objects.

```
obj: word: agent:
o0   (li)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
o1   (yu)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
o2   (pi)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
o3   (do)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
o4   (vi)  [ a0 a1 a3 a4 a5 a6 a7 a8 a9 ]
     (nu)  [ a2 ]
o5   (yi)  [ a0 a1 a3 a4 a5 a6 a7 a8 a9 ]
     (nu)  [ a2 ]
o6   (fa)  [ a0 a1 a5 a6 a7 a9 ]
     (na)  [ a2 a3 a4 a8 ]
o7   (se)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
o8   (va)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
o9   (su)  [ a0 a1 a2 a3 a4 a5 a6 a7 a8 a9 ]
```

Figure 7: Language formed through contact of two languages containing different objects.

```
obj: word: agent:
o0   (li)  [ a0 a1 a2 a3 a4 a5 ]
o1   (yu)  [ a0 a1 a2 a3 a4 a5 ]
o2   (pi)  [ a0 a1 a2 a3 a4 a5 ]
o3   (do)  [ a0 a1 a2 a3 a4 a5 ]
o4   (vi)  [ a0 a1 a2 a3 a4 a5 ]
o5   (ce)  [ a0 a1 a2 a3 a4 a5 ]
o6   (fa)  [ a0 a1 a2 a3 a4 a5 ]
o7   (yi)  [ a0 a2 a3 a5 ]
     (va)  [ a1 a4 ]
o8   (se)  [ a0 a1 a2 a3 a5 ]
     (va)  [ a4 ]
o9   (qu)  [ a0 a1 a2 a3 a4 a5 ]
```

Figure 9: Language formed through contact of two languages containing different objects.

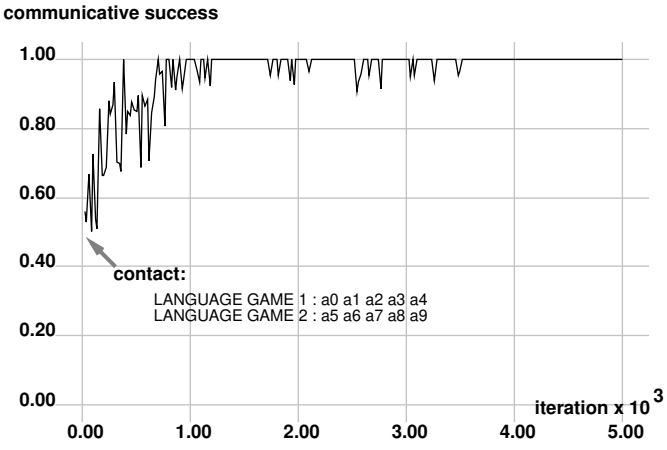

Figure 8: Adaptation of language after contact.

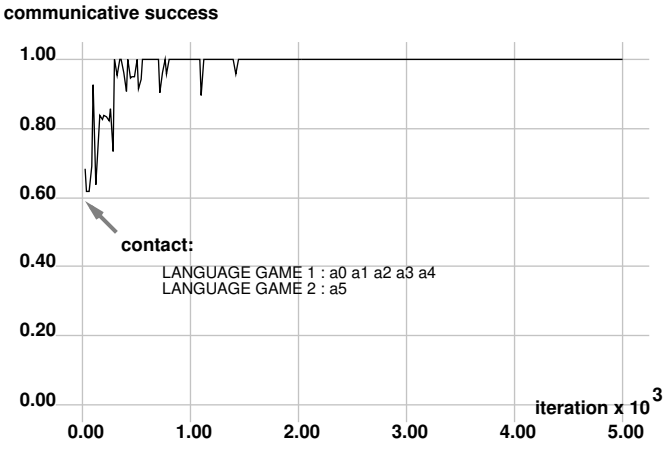

Figure 10: Adaptation of language after contact.

4.3 Contact of languages containing incoherence and ambiguity

So far we have not taken account of contact of languages which contain incoherence and ambiguity, although these characteristics appear quite typically in the model used here. Contact of languages with incoherence and ambiguity is illustrated in this section.

Figure 11 shows two typical languages formed through different series of games. LANGUAGE_GAME_1 (hereinafter referred to as LG1) has incoherence for o_7, o_8 for which several words are used by the group, and has ambiguity for "ki" which can mean both o_2 and o_5. LANGUAGE_GAME_2 (hereinafter referred to as LG2) has incoherence involving o_5, o_7, and ambiguity of "di". Moreover, "he" becomes ambiguous if the two languages are in contact, because it exists in both LG1 and LG2.

Note that $o_5 \sim o_9$ exists in both LG1 and LG2, while $o_0 \sim o_4$ and $o_{10} \sim o_{14}$ exist only in LG1 and LG2, respectively.

Figure 12 shows a language formed among agents after 10000 iterations of the language game since their worlds have contacted (the adaptation process is shown in Figure 13). In this case, we have selected a_0, a_1, a_2, a_3, a_4 from LG1 and a_5, a_6 from LG2 to make contact, so that major and minor groups of agents exist.

Similar tendencies are apparent here as in section 4.1, 4.2 but the results differ in a few points as described below:

- In the case where there is some incoherence and ambiguity, language adapts itself to a language which has less incoherence and ambiguity by borrowing words directly or indirectly from another language, or by creating new words.

The symbol "*" in Figure 12 indicates the meanings that had incoherence and ambiguity before contact. We can see that these characters are reduced through contact by borrowing and creating words.

o_2 had existed only in LG1 so that it ought to be called "ki" after contact, which is a word used in the major group. The word "ki", however, was ambiguous in LG1 and "lo", which was associated with o_6 in the minor group (LG2), has consequently come indirectly to be used for o_2, and ambiguity of this meaning has been removed.

o_5 had existed in both groups so that it also ought to be called "ki", which is a word used in the major group, after contact, but this word was ambiguous. Consequently, a word "di" which was associated with the same object in the minor group (LG2) has come to be used directly for the object.

o_7 and o_8 ought to be associated with words used in major group, but words associated with these objects were incoherent in LG1. Thus, a new word "ko" was created and has come to be used for o_7. Close inspection shown that "ko" was first created by a_2 not for o_7 but for o_{14}. The incoherence of o_8 has been removed by the major group borrowing "bi" directly from the minor group.

o_{14} existed first only in LG2 so that a word "he", which was associated with this object in LG2, ought to be used after contact. However, "he" becomes ambiguous after contact because it also exists in LG1, so another word, "co" which was used in LG1 has come to be associated with the object.

These tendencies described above will not change even if both groups of agents are equal in size.

5 Conclusion

Using a simple "language game" model, we have focused on the dynamic aspects of "languages". Firstly, we observe the processes of emergence and development of language among multiple communicative agents. The languages formed through such "self-organizing" processes have been proven to be able to adapt to changes of the world; for example, when new agents or unknown objects come into the world [7, 9].

In addition to the above preliminary observation, we subsequently bring different languages, developed separately by distinct groups of agents, into contact with each other. Our experimental results show that the adaptability of the language enabled it to "self re-organize" into a more coherent one. Concretely, we observe the following results: (1) the language of a majority group tends to be used, (2) "language borrowing" may occur when agents need to refer to meanings that have not previously been familiar to them, and (3) languages with incoherence or ambiguity tend to be more distinct through the processes of "language contact."

These kinds of contact processes can also be observed in real languages. There are many bilingual individuals in our world; therefore, each language is always exposed to opportunities of contact with others. When we need to refer to a new object or a new concept which we have no means to express with our own language, we tend to borrow the "words" from another language that expresses the corresponding concept. Such necessity arises at any time when we come into contact with other cultures, such as new information and technologies, animals and plants of other places, and so on [4]. Pidgin and creole may be much more drastic examples of language contact. The adaptation that occurs in that case might not be merely a "self re-organizing" of language, but also an instance of the "evolution of language".

Since the model used in this paper is an extremely abstract one that simplifies a number of important factors residing in real languages and our human societies, our results may not give perfect explanations for the language borrowings or evolutionary processes of pidgin or

```
        --LANGUAGE_GAME_1--                    --LANGUAGE_GAME_2--
obj: word: agent:                      obj: word: agent:
o0   (bu)  [ a0 a1 a2 a3 a4 ]          o5   (di)  [ a5 a6 a8 a9 ]
o1   (ha)  [ a0 a1 a2 a3 a4 ]               (la)  [ a7 ]
o2   (ki)  [ a0 a1 a2 a3 a4 ]          o6   (lo)  [ a5 a6 a7 a8 a9 ]
o3   (he)  [ a0 a1 a2 a3 a4 ]          o7   (di)  [ a5 a6 a7 a9 ]
o4   (ce)  [ a0 a1 a2 a3 a4 ]               (na)  [ a8 ]
o5   (ki)  [ a0 a1 a2 a3 a4 ]          o8   (bi)  [ a5 a6 a7 a8 a9 ]
o6   (ni)  [ a0 a1 a2 a3 a4 ]          o9   (se)  [ a5 a6 a7 a8 a9 ]
o7   (qe)  [ a0 ]                      o10  (po)  [ a5 a6 a7 a8 a9 ]
     (ni)  [ a1 a4 ]                   o11  (na)  [ a5 a6 a7 a8 a9 ]
     (co)  [ a2 a3 ]                   o12  (la)  [ a5 a6 a7 a8 a9 ]
o8   (co)  [ a0 a1 a2 a3 ]             o13  (do)  [ a5 a6 a7 a8 a9 ]
     (ce)  [ a4 ]                      o14  (he)  [ a5 a6 a7 a8 a9 ]
o9   (qe)  [ a0 a1 a2 a3 a4 ]
```

Figure 11: The typical appearance of languages formed through different series of games. Each language involves incoherence and ambiguity.

```
 obj: word: agent:
 o0   (bu)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o1   (ha)  [ a0 a1 a2 a3 a4 a5 a6 ]
*o2   (lo)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o3   (he)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o4   (ce)  [ a0 a1 a2 a3 a4 a5 a6 ]
*o5   (di)  [ a0 a1 a2 a4 a5 a6 ]
      (ki)  [ a3 ]
 o6   (ni)  [ a0 a1 a2 a3 a4 a5 a6 ]
*o7   (ko)  [ a0 a1 a2 a3 a4 a5 a6 ]
*o8   (bi)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o9   (qe)  [ a0 a2 a3 a4 a5 a6 ]
      (se)  [ a1 ]
 o10  (po)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o11  (na)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o12  (la)  [ a0 a1 a2 a3 a4 a5 a6 ]
 o13  (do)  [ a0 a1 a2 a3 a4 a5 a6 ]
*o14  (co)  [ a0 a1 a2 a3 a4 a5 ]
      (he)  [ a6 ]
```

Figure 12: Language formed through contact of two languages containing incoherence and ambiguity.

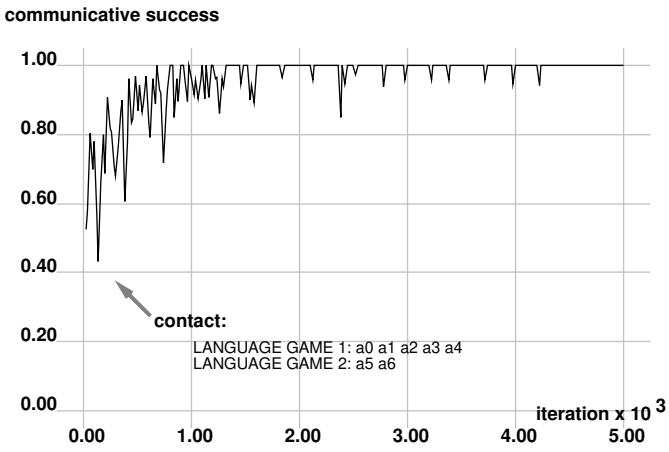

Figure 13: Adaptation of language after contact.

creole in the real world. Nevertheless, even our simple model may suggest possible explanations for the complexity of "languages", including fluidity, diversity, openness, adaptiveness, and so on.

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