EXPLORING THE ROLES OF MAJOR FORMS OF CULTURAL TRANSMISSION IN LANGUAGE EVOLUTION

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Cultural transmission is the primary medium of linguistic interactions. We propose an acquisition framework that involves the major forms of cultural transmissions, such as vertical, oblique and horizontal transmissions. By manipulating the ratios of these forms of transmission in the total number of transmission across generations of individuals, we analyze their roles in language evolution, based on a lexicon-syntax coevolution model. The simulation results indicate that all these forms of transmission collectively lead to the dynamic equilibrium of language evolution across generations.

1. Introduction

Human language is transmitted mainly via *cultural transmission* (the process of language adaptation in a community via various kinds of communication among individuals of the same or different generations, Christiansen & Kirby, 2003). Generally speaking, there are three forms of cultural transmission: a) *horizontal transmission (H)*, communications among individuals of the same generation; b) *vertical transmission (V)*, in which a member of one generation talks to a biologically-related member of a later generation; and c) *oblique transmission (O)*, in which any member of one generation talks to any non-biologically-related member of a later generation. Besides empirical studies, computational modeling that incorporates these forms of transmission has joined the endeavour to tackle problems of language evolution. This line of research has started from the Iterated Learning Model (ILM, Kirby, 2001), in which V transmission across single-individual generations is simulated and a limited exposure to the previous generation's linguistic instances is shown to trigger the origin of a compositional language in the future generation's language learner (*the bottleneck effect*). This effect is also shown in a laboratory experiment (Kirby et al., 2008) and proved in some Bayesian learning models (e.g., Kirby et al., 2007). Some later versions of ILM (e.g., Smith & Hurford, 2003) started to incorporate multi-agent generations and both V and O transmissions.

Meanwhile, some new models have been developed (e.g. Vogt, 2005), which uses two probability parameters to restrict the choices of speakers and listeners from adults or children during transmission. However, this probability approach implicitly involves the child-talking-to-adults transmission, which contaminates the effects of other forms on language evolution (Gong et al., in press).

In this paper, we modify this probability approach by proposing three parameters to control respectively the probabilities of H, V, and O transmissions. In this acquisition framework, children can talk to each other via H transmission, and adults talk to children via V or O transmission. These probability parameters are less dependent on the actual numbers of transmission and the particular language models. We use a ternary plot to vividly show that each form of transmission has its respective role in language evolution and all these forms have collectively led to a dynamic equilibrium of language evolution. The rest of the paper is organized as follows: Sec. 2 briefly reviews the language model; Sec. 3 describes the acquisition framework and simulation setup; Sec. 4 discusses the simulation results; and Sec. 5 gives the conclusions.

2. The Lexicon-Syntax Coevolution Model

This model was designed to study if a population of interacting *individuals* (artificial agents), based on some general learning mechanisms, can develop a compositional language out of a holistic signaling system (Gong, 2009). The evolved communal language is *systematic*, consisting of a set of lexical items and simple consistent word order(s). This model has two key features. First, it simulates the development of idiolects. Based on pattern extraction, individuals extract recurrent patterns in exchanged utterances into lexical items; based on semantic and sequential guidance of lexical items in exchanged utterances, individuals categorize lexical items with identical semantic roles and similarly ordered with respect to other lexical items in utterances; and based on categories and local orders among them, individuals form up global orders to regulate lexical items and encode simple predicate-argument meanings (Hurford, 2007) in utterances. The linguistic knowledge is represented by lexical rules, syntactic rules, and categories. Second, this model implements an *implicit meaning transfer* during dyadic transmission. Both the speaker and the listener refer to their own linguistic knowledge in production and comprehension. In production, the speaker can randomly create a holistic rule to map the chosen meaning, if its linguistic knowledge fails to encode that meaning; in comprehension, besides linguistic knowledge, some nonlinguistic, *unreliable* cue (which may or may not contain the speaker's intended meaning) may assist interpretation. Based on a

standard, strength-based competition, individuals select their linguistic rules among the competing ones. Without direct meaning check, if the combined strength of the listener's used rules exceeds a *confidence threshold*, both individuals award their used rules (by increasing their strengths) and penalize (by decreasing their strengths) other competing ones; otherwise, both penalize their used rules in this transmission. In this way, the linguistic knowledge of these two individuals will become similar, which resembles the process of *conventionalization* (a social agreement for meaning–utterance associations). Both of these features make this model suitable to simulate language acquisition in children, and provide an appropriate level of complexity to discuss the role of cultural transmission in language evolution. Please refer to Gong (2009) for a detailed description of the major components, the transmission scenario, and the adopted learning mechanisms of this model, and a systematic discussion of the effects of various parameters that control those learning mechanisms.

3. The Language Acquisition Framework

Fig. 1 shows this framework. In each generation, a fixed number of randomly chosen adults each produce an offspring (child) that initially has no linguistic knowledge. Then, during a learning stage, each child develops his/her idiolect by learning from an adult via Parent-to-Child (V) or Adult-to-Child (O) transmission or from another child via Child-to-Child (H) transmission. The ratios of these forms are respectively manipulated by *PCrate*, *ACrate* and *CCrate*. During transmission, there is no global fitness guiding a child to learn from a specific adult or child. After the learning stage, children become adults and replace their parents, and a new generation begins.

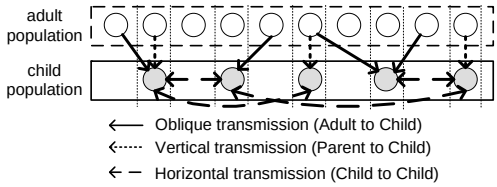


Figure 1. The acquisition framework that involves the three major forms of cultural transmission.

Strictly speaking, this is a pure cultural evolution setup without inheritance of biological features during reproduction. But it is still necessary to distinguish V and O transmissions. If there is more than one of V transmission, a child keeps sampling from its parent. If there is more than one of O transmission, however, a child can sample from more than one adult. Considering that this

child may interact with the offspring of those adults in H transmission, O transmission may play a different role from V transmission on language evolution. In addition, it is necessary to distinguish adults and children. Considering *the critical period hypothesis* (Penfield and Roberts, 1959), we assume that only children update their linguistic knowledge in transmission, adults do not. Then, H transmission is distinct from V and O transmissions. Furthermore, PCrate, ACrate and CCrate control the percentages of different forms of transmission in the total number of transmission involving multiple individuals during the learning stage, instead of the number of transmission in which a particular new child is involved.

Table 1. The parameter settings. The left table lists the basic parameters for communications and acquisition framework. Please refer to Gong (2009) for the discussion of the effects of parameters for communications. The right table lists the 54 cases in each set of simulations. There are three extreme cases: the case of purely horizontal transmission (PCrate=ACrate=0.0, CCrate=1.0) is excluded, since it is obvious that in this case no language is transmitted across generations and children in each generation are creating their own communal language via horizontal transmission; the case of purely vertical transmission (PCrate=1.0, ACrate=CCrate=0.0) is discussed separately in Sec. 4, and so as the case of purely oblique transmission (PCrate=CCrate=0.0, ACrate=1.0).

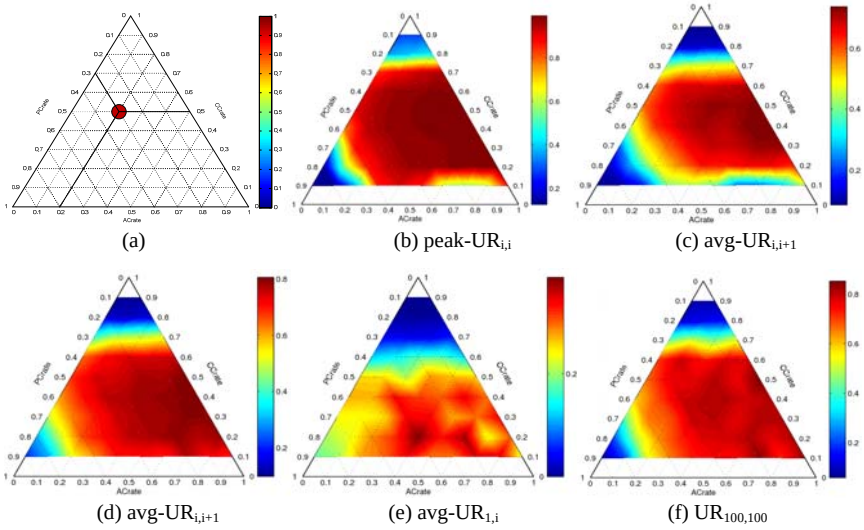
	Parameters	Values
For communications	Semantic space	64
	Individual memory size for lexical rules	60
	Individual memory size for categories	20
	Individual memory size for syntactic rules	20
	Extraction rate of lexical/syntactic rules	0.25
	Creation rate of holistic rules	0.25
	Strength adjustment in competition	0.1
	Amount of strength adjustment in forgetting	0.01
	Reliability of cue	0.6
	Confidence threshold	0.75
	No. of utterance exchange per transmission	20
For the acquisition framework	Population size	10
	No. of adults each producing 1 offspring	5
	No. of transmissions in the learning stage	200
	No. of generations	100

Cases	PCrate	ACrate	CCrate
1	0.0	0.1	0.9
2	0.0	0.2	0.8
3	0.0	0.3	0.7
⋮			
9	0.0	0.9	0.1
10	0.1	0.0	0.9
11	0.1	0.1	0.8
⋮			
18	0.1	0.8	0.1
19	0.2	0.0	0.8
⋮			
51	0.7	0.2	0.1
52	0.8	0.0	0.2
53	0.8	0.1	0.1
54	0.9	0.0	0.1

The roles of different forms of transmission on language evolution are studied based on the understandability of the communal language. We define three indices: a) *understanding rate (UR) within a particular generation* ($UR_{i,i}$), calculating the average percentage of integrated meanings understandable to each pair of individuals after the learning stage, based only on their linguistic knowledge; b) $UR_{i,i+1}$, calculated as UR between individuals from Generations i and $i+1$; and c) $UR_{1,i}$, calculated as UR between individuals from Generations 1 and i. High $UR_{i,i+1}$ indicates that a communal language is accurately understood by individuals across consecutive generations. High $UR_{1,i}$ indicates that an initial language is largely preserved in later generations. We conduct two sets of simulations, whose parameter settings are listed in Table 1. In the first set, the

adults in Generation 1 only share a limited number of holistic rules to express few integrated meanings; in the second set, the adults in Generation 1 share a compositional language capable of expressing all integrated meanings. In each set, 54 cases are considered based on *PCrate*, *ACrate* and *CCrate* (see Table 1).

4. The Simulation Results



(a) (b) peak-$UR_{i,i}$ (c) avg-$UR_{i,i+1}$

(d) avg-$UR_{i,i+1}$ (e) avg-$UR_{1,i}$ (f) $UR_{100,100}$

Figure 2. (a) The patch corresponds to the case PCrate=0.3, ACrate=0.2, CCrate=0.5, and its value is 1.0, based on the color map beside). (b)(c): the simulation results in the first set of simulations. (d)-(f): the simulation results in the second set of simulations. Each value is calculated based on 20 runs.

We adopt surface ternary plots to show the results. Figure 2 shows how to read in such plots and the results of the two sets. For the first set, we measure peak-$UR_{i,i}$ and avg-$UR_{i,i+1}$ in 100 generations; for the second set, we measure avg-$UR_{i,i+1}$ and avg-$UR_{1,i}$ in 100 generations. In the second set, peak-$UR_{i,i}$ appears in Generation 1, since all adults initially share a common compositional language. Therefore, we measure $UR_{100,100}$. The tendencies shown in these results are less dependent on the number of transmission during the learning stage and the number of individuals replaced in each generation, except that the absolute values of those indices in different settings could be different.

These results can be analyzed based on the UR values in different regions of the plots. Near the left angle, V transmission is dominant (PCrate is high, ACrate and CCrate are low), and the low UR values show that if the learning stage has mainly V transmission, both the origin of a common language with

good understandability and the maintenance of an initial compositional language cannot be achieved. A further check based on the simulations with different numbers of purely V transmission (PCrate=1.0, ACrate=CCrate=0.0) confirms this finding (Gong et al., in press). It differs from the finding in ILM (e.g., Smith & Hurford, 2003), where purely V transmission can trigger a communal language with good understandability. This difference is due to the implicit meaning transfer in our language model. In the first set, while talking to children, adults in early generations, due to lacking linguistic knowledge, have to introduce new expressions. Since children have no linguistic knowledge, comprehension of these expressions relies on cues, and the occasional "wrong" cues having meanings different from adults' intended ones may cause children to develop some salient knowledge. Without V or O transmission, children develop independently their linguistic knowledge. After they replace adults and talk to new children, the idiolects among individuals will continue to diverge. In the second set, adults in Generation 1 have already shared some linguistic knowledge, but the unreliable cues still cast their influence, especially when adults talk to children not yet acquiring much linguistic knowledge. Without other forms of transmission, this influence could accumulate to such an extent that the communal language after a few generations becomes quite distinct from the initial one. Therefore, purely V transmission in a multi-individual population fails to trigger or maintain a communal language with good understandability.

Near the top angle, H transmission is dominant (PCrate and ACrate are low, CCrate is high), during which children can be either speakers or listeners, and both speakers and listeners update their linguistic knowledge. This two-way conventionalization is efficient to spread linguistic knowledge among individuals, thus helping their idiolects to converge. H transmission is good at maintaining high understandability within generations, and the two-way conventionalization may help diffuse some salient linguistic knowledge to the population, thus introducing changes in the communal language. However, H transmission occurs only among children, without sufficient other forms of transmission to get a broad sample of adults' language, what children develop in H transmission is a set of salient rules different from those of the adults. After being adults, without sufficient V or O transmission, they cannot provide enough instances of their idiolects to new children, who will keep randomly creating their own idiolects. Therefore, as shown by the low UR values, a communal language with good understandability cannot be preserved across generations via mainly H transmission.

Near the right angle, O transmission is dominant (PCrate and CCrate are low, but ACrate is high). This form of transmission has a similar role as V transmission by providing children with instances of the previous generation's language, but it allows one child to sample from multiple adults, thus making it more efficient than V transmission to spread linguistic knowledge of multiple individuals to new children. This results in the higher UR values in this angle than those in the left. In addition, only children update their linguistic knowledge in O transmission, adults do not. This one-way conventionalization of idiolects is less efficient than H transmission, which explains why the UR values in the first set are lower than those in the second set of simulations. A further check of simulations with purely O transmission shows that the UR value in this case is lower than those in the regions with many rounds of O transmission but a few of H transmission, which suggests the necessity of other forms of transmission, such as H transmission.

These three regions illustrate the relative roles of V, O, and H transmissions on language evolution. In all these plots, the highest UR values are obtained in the regions with some low values of PCrate but high values of either ACrate or CCrate. This shows that either V or O transmission is necessary for spreading language across generations and H transmission is also needed to maintain the understandability of the communal language within generations. In addition, during these forms of transmission, some salient knowledge may diffuse to the whole population, which introduce changes in the communal language, which causes the maximum values of $UR_{1,i}$ in these plots are not much high, compared with $UR_{i,i}$ and $UR_{i,i+1}$. All these results indicate that all these forms of transmission are necessary to trigger a communal language with good understandability and to largely preserve an initial communal language across generations. They also reveal a *dynamic equilibrium* of language evolution: in a cultural environment involving sufficient these three forms of transmission, individuals from consecutive generations can well understand each other ($UR_{i,i+1}$ is high), but language change is inevitable in the long run (UR_{ini} is not high). This equilibrium is collectively achieved by these three forms of transmission.

5. Conclusions

This paper proposes a multi-agent acquisition framework to discuss the roles of three major forms of cultural transmission in language evolution. Both V and O transmissions help maintain an initial language to a certain extent, and H transmission is necessary for maintaining the understandability of the communal language and diffusing linguistic variation. A reasonable combination of these

forms of transmission can not only efficiently trigger a communal language but also largely maintain it across generations of language learners. These findings are insightful on research of other cognitive, political or economic activities that are also culturally transmitted. And the current framework can be modified to involve other forms of transmission (e.g., grandparent-grandchild transmission) or adopt continuous generation replacement or family structures. Both of these can help better understand the role of cultural factors on language evolution.

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