The Ising Model for Changes in Word Ordering Rule in Natural Languages

Yoshiaki Itoh and Sumie Ueda
The Institute of Statistical Mathematics
4-6-7 Minami-Azabu, Minato-ku, Tokyo 106-8569, Japan

Abstract

The order of ‘noun and adposition’ is the important parameter of word ordering rules in the world’s languages. The seven parameters, ‘adverb and verb’ and others, have a strong dependence on the ‘noun and adposition’. Japanese as well as Korean, Tamil and several other languages seem to have a stable structure of word ordering rules, as well as Thai and other languages which have the opposite word ordering rules to Japanese. It seems that each language in the world fluctuates between these two structures like the Ising model for finite lattice.

Model of changes of word ordering rules and Tsunoda’s table

Natural languages have been attractive objects of various interdisciplinary studies. The problem how the universals of languages evolve is drawing the attention of the physicists. The importance of adpositions (prepositions and postpositions) as a parameter is recognized in word order typology. In previous studies using the word order data of Tsunoda (Table.1), in which Japanese is taken as the standard of comparison, 130 languages are classified by using 19 word order parameters. The result is that the 130 languages are neatly divided into two groups with one exception or two: (a) prepositional languages and (b) other languages, i.e. postpositional languages and adpositionless languages. Adpositionless languages behave like postpositional languages in terms of other word order parameters. The second important parameter of word order is ‘numeral and noun’. Applying a statistical method for categorical data, the clustering of the 130 languages is well explained by the two word ordering parameters, ‘noun and adposition’ and ‘numeral and noun’.

Greenberg utilizes the position of adpositions in seven of the forty five universals he proposes (pp.110-12). For example in languages with prepositions, the genitive almost always follows the governing noun, while in languages with postpositions it almost always precedes it. Tsunoda’s data show, the parameters 1 (S, O and V), 3 (genitive and noun), 7 (relative clause and noun), 8 (proper noun and common noun), 9 (comparison of superiority), 10 (main verb and auxiliary verb) and 19 (purpose clause and main clause), have strong dependence on the parameter 2 (noun and adposition). For example our study of the data gives the statistical laws on cooccurrence with three parameters.

(i) If a language has preposition, and if the language is the VO language, then the genitive tends to follow the noun.
Table 1: Word order data by Tsunoda (1991). For parameter 2 ‘noun and adposition’ to parameter 10 ‘Main verb and auxiliary verb’, and also for parameters 18 ‘Conditional clause and main clause’ and 19 ‘Purpose clause and main clause’, the plus sign ‘+’ and minus sign ‘−’ are used — wherever possible — with Japanese as the standard of comparison. (This ‘+/−’ method is used for some other parameters as well when applicable.) Japanese is convenient as the standard of comparison. Thus, if a given language has ‘noun+postposition’ like Japanese, then it will be assigned ‘+’ for parameter 2. If a given language has ‘Preposition+noun’ in contrast with Japanese, it will be assigned ‘−’ for this parameter. If a given language has some other order, then an explanation is given as much as possible. If such an explanation is not feasible, it is simply presented as ‘Other’. If a given language has two orders, such as ‘Adjective+noun (+)’ and ‘noun+adjective (−)’, then the order that appears to be the more common is presented first. Thus, if ‘Adjective+noun’ is more common than ‘noun+adjective’ in a given language, we have ‘+/−’ rather than ‘−/+’ for the parameter ‘Adjective and noun’ of this language. When a given language has alternative possibilities other than the word order listed, this is shown with ‘etc.’. The expression ‘NA (not available)’ indicates that no information is available.

| No. | Word order parameters | Japanese | English | Thai | Panjabi |
|-----|----------------------|----------|---------|------|---------|
| 1   | S, O and V           | SOV, etc.| SVO     | SVO  | SOV     |
| 2   | Noun and adposition | +        | −       | −    | +       |
| 3   | Genitive and noun    | +        | +, −    | −    | +       |
| 4   | Demonstrative and noun| +    | +       | −    | +       |
| 5   | Numeral and noun     | +        | +       | −    | +       |
| 6   | Adjective and noun   | +        | +       | −    | +       |
| 7   | Relative clause and noun | + | −     | − | other; + |
| 8   | Proper noun and common noun | + | −, + | − | NA (not available) |
| 9   | Comparison of superiority | + | − | − | + |
| 10  | Main verb and auxiliary verb | + | − | −, + | + |
| 11  | Adverb and verb      | before V | various | various | immediately after S |
| 12  | Adverb and adjective | +        | +, −    | −    | +       |
| 13  | Question marker      | sentence-final | none | sentence-final, immediately after focus of question | none |
| 14  | S,V inversion in general questions | none | present | none | none |
| 15  | Interrogative word   | declarative | sentence-initial | declarative | immediately before verb |
| 16  | S,V inversion in special questions | none | present | none | none |
| 17  | Negation marker      | verbal suffix | immediately after verb | immediately before focus of negation | immediately before verb |
| 18  | Conditional clause and main clause | + | +, − | −, + | + |
| 19  | Purpose clause and main clause | + | − | − | − |
If a language has postposition, and if it is the OV language, the genitive tends to precede the noun.

(ii) If the main verb of a language follows the auxiliary verb, and if the relative clause follows the noun, the purpose clause tends to follow the noun.

If the main verb of a language precedes the auxiliary verb, and if the relative clause precedes the noun, the purpose clause tends to precede the noun.

We study the cooccurrence of word ordering rules of the world’s languages by using the idea of the Ising model. It is well known that the spontaneous magnetization can occur in the thermodynamic limit only. In a finite lattice, the system makes excursions from states with uniformly negative magnetization through this intermediate mixed-phase state to states with uniformly positive magnetizations [3]. Our ternary interaction model of a finite population makes similar excursions assuming a mutation to the other type for each particle. Consider a system of particles of two types $A$ and $B$. At each step, three particles are taken at random. If two of the three particles are of the type $A$ ($B$) and one is of the type $B$ ($A$), the three particles become three particles of the type $A$ ($B$) with probability $p$ and the three particles of the type $B$ ($A$) with probability $1 - p$. We continue this step sequentially. Hence, if $p$ is larger than $1/2$, the type of the majority is advantageous to the type of the minority. If $p$ is less than $1/2$, the type of the minority is advantageous. The model for the $p$ less than $1/2$ might be a simple caricature of the Ising model for the temperature higher than the critical point, although the model does not have space variables neglecting the position of each particle. The case of the $p$ higher than $1/2$ corresponds to the Ising model for the temperature lower than the critical point, where the majorities are advantageous to the minorities. Here we apply the ternary interaction model to study word ordering rules of the world 130 languages [2].

A pair of very similar word orders may appear just by chance. For instance, the difference between Tamil and Japanese is as small as the difference between Italian and Spanish in Tsunoda’s word order table [2]. Japanese as well as Korean, Tamil and several other languages seem to have a stable structure of word ordering rules. We put the value $+1$ for each of the eight parameters ‘noun and adposition’ and the above seven parameters for Japanese. We put $-1$ for each of the eight parameters for the languages which have the opposite word ordering rules like Thai. The changes in the values of the parameters of each language may depend on the values of other parameters as can be seen from the above i), and ii) for three parameters. It seems that each language in the world fluctuates between these stable two structures. Hence the system of word ordering rules in Thai, or the opposite system like Japanese, Korean, Mongolian and others seem to be reasonable considering the above ternary interaction model of the majority rule, and may be explained by economy of communications to avoid misunderstanding. Each language in the world has its own history and personality. Word ordering rules of each language may change at random like a mutation in a population of eight individuals each of which corresponds to a parameter of word ordering rules. The biological mechanism for performing language may be ultimately functionally driven by the need for rapid and efficient communications in real time [1]. Hawkins [5] discusses the relationship between innateness and functional pressures in the explanation of language universals and argues some innate processing mechanism have responded to functional pressure that make rapid and efficient communications possible. This observation may support our stochastic model for the change of word ordering rule. It seems that each language fluctuates between the above stable two structures like the Ising model for finite lattice. The fractal structure [10] is
useful to understand the structure of sentences. The parse tree is convenient to represent the phrase structure rule in generative grammar. English is a prepositional language and Japanese is a postpositional language. English sentences are usually represented by left branching parse trees, while Japanese sentences are represented by left branching parse trees. Evolution of word ordering rules or evolution of parse trees, which may be closely related with each other, are interesting problems and will be discussed by using evolutionary game theory.

**Simulation and data** We consider the numerical values of the above eight parameters. For the parameters of each language that can not clearly be classified into +1 or −1, we give a numerical value between +1 and −1 by a digitization of the description in Table 1. We take the summation of the numerical values of the eight parameters for each language and divide the value by eight to take the arithmetic mean. We take the arithmetic mean for the summation of the existing values of parameters when there are missing values. We call the arithmetic mean as the measure of Postposition-ness. Figure 1 shows the histogram of the measure of “postposition-ness” considering the eight parameters for the 130 languages.

Figure 1: The histogram for the measure of “postposition-ness” considering the eight parameters on the 130 languages (from Ueda ans Itoh (1995)).

The changes of word ordering rules could be modeled as the above ternary interaction.
model of eight particles 1, 2, ..., 8, assuming that \( p = 1 \) and the mutations for each particle changing its sign occur at a certain rate at the end of each step. The trajectory of the number \( n_+ \) of particles of the type +1 is given in Figure 2a for the first 500 steps, assuming a mutation to the opposite sign occurs in the system of eight particles with probability 0.5 for a particle chosen at random at each step. The histogram for the numbers of visits has two modes as shown in Figure 2b.

We represent word ordering rules of each of 130 languages by a vector of 66-dimension. We define a Manhattan distance \( d \) between two languages as eq. (1) given later. We make a random walk on the 130 languages to simulate changes of word ordering rules. We take a language at random at first. Then we take the second language at random from languages within a given Manhattan distance \( d = 0.6 \) from the first language. We take the third language at random from languages within the distance \( d = 0.6 \) from the second language. We continue this random walk and obtain the trajectory given in Figure 3a for the first 500 steps. The histogram on the number of visits for the arithmetic mean also has two modes in Figure 3b as in Figures 1 and 2b for the first 2000 steps. The states in which the eight parameters have the same sign, seem to be relatively stable in the random walk.

**Conclusion** Our present study on Tsunoda’s table may give a possible answer to an aspect of the problem how the language universals evolve. The word ordering rule may change at random by getting functional pressure that make rapid and efficient communications possible. The word ordering rule of each language in the world seems to fluctuate between the two stable structures, a typical postpositional language structure and a typical prepositional language structure, like the Ising model for finite lattice.

**Methods for the digitization of Tsunoda’s Table**

We make a 66-dimensional vector for each language to digitize the word order data. In the data by Tsunoda ‘NA’ is used for the case that the author of the book [2] had not enough knowledge to give the description for a parameter of a language at the time of publication of the data. Our present study is based on the data by Tsunoda [2] as in the previous study [4]. Our method can be extended to define the distance between two languages including “NA”, applying the idea in the S language [13], although we do not explain it in this article.

A numerical value between 0 and 1 was assigned to each of the 19 parameters according to the description of word orders concerned. The total of the elements within a parameter should be 1, i.e.

\[
\sum_{m=1}^{n_k} x_{i,k,m} = 1,
\]

for \( i = 1, \ldots, 130, k = 1, \ldots, 19 \), where \( n_k \) is the dimension of parameter \( k \) and \( x_{i,k,m} \) is the value of the \( m \)-element of parameter \( k \) of language \( i \).

We represent the state of the parameter 1 by the 2-dimensional vector for the six possible combination of the parameter S,O and V. The OV language contains SOV, OSV and OVS languages. The VO language contains SVO, VSO and VOS. In the case of Japanese, which has ‘SOV, etc.’, (1, 0) is assigned. In the case of English, which has ‘SVO’, (0, 1) is assigned. And also, in the case of Modern Greek, which has ‘SVO, VSO, etc.’, (0, 1) is assigned. For a parameter with a 3-dimensional vector, we represent it by (1, 0, 0) if the order is the same to Japanese. If it is the reversed order to Japanese, we represent it by (0, 1, 0). Otherwise we represent it by (0, 0, 1). For example, the parameter 3 (genitive and noun) for English is ‘+, −’ which is represented by (0.6, 0.4, 0). When a
Figure 2: The simulation of the majority rule model. a: The trajectory. b: The histogram with two modes for numbers of visits by the trajectory, assuming a mutation to the opposite sign at each step.
Figure 3: The random walk on the 130 languages. a. The trajectory of the first 500 steps starting from Japanese. b. The histogram of the numbers of visits by the trajectory.
parameter of a language has more than one word order possibility, the ratio is given by the similarity of the competing possibilities. We use 6-, 5- and 13-dimensional vectors, respectively for the parameters, 11, 13 and 17. For each of the 130 languages, we make a 66-dimensional vector from the 19 vectors by arranging the coordinates of the 19 vectors from the vector for parameter 1 to the vector for parameter 19. We give two examples for the digitization. The 19 slashes in the following vector classify the 66 coordinates into the 19 parameters.

Japanese:

\[(1, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0)\]

English:

\[(0, 1/0, 1/0, 0/6, 0/4, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1, 0, 0/1)\]

We define the distance between two languages \(i\) and \(j\) as

\[
d(i, j) = \frac{1}{19} \sum_{k=1}^{19} \sum_{m \in n_k} |x_{i,k,m} - x_{j,k,m}| \leq 2.\quad (1)
\]

The distances between English and Japanese, between English and Thai, and between Japanese and Thai are 1.45, 1.05, and 1.52. By using the S language using the above distances we derived the hierarchical clustering for the Eurasian languages (Figure 4).

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Figure 4: The hierarchical clustering for the Eurasian languages using the distance metric $d^*$ applying the furthest method in S language (from Tsunoda, Ueda, and Itoh (1995)).

49 languages (Eurasian) - all parameters / manhattan / furthest
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