Network of two-Chinese-character compound words in Japanese language

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Abstract

Some statistical properties of a network of two-Chinese-character compound words in Japanese language are reported. In this network, a node represents a Chinese character and an edge represents a two-Chinese-character compound word. It is found that this network has properties of “small-world” and “scale-free.” A network formed by only Chinese characters for common use (joyo-kanji in Japanese), which is regarded as a subclass of the original network, also has small-world property. However, a degree distribution of the network exhibits no clear power law. In order to reproduce disappearance of the power-law property, a model for a selecting process of the Chinese characters for common use is proposed.

1 Introduction

It has been found that a great variety of systems, such as internet [1, 2], collaboration in science [3, 4], food web [5, 6], have network structures; systems consist of a group of nodes which interact mutually through edges. Network science supplies some methods to understand topological structures of such systems. Recently, it has been proved that the properties of small-world [7, 8] and scale-free [9] are important and that many networks share these properties. For typical examples, human languages have been modeled in the framework of complex networks so as to investigate graphemic [10], phonetic [11], syntactic [12] and semantic [13] structures.

Chinese characters are main elements in the writing system of Japanese language. One of the most remarkable features of Chinese characters is that they are ideograms, that is, a single Chinese character can convey its own meaning.

Japanese language possesses many words constructed by combining two Chinese characters. Such words are called ‘two-Chinese-character compound words’ (niji-jukugo in Japanese), and we adopt the name ‘two-character compounds’ hereafter. For instance, in the Japanese-language dictionary Kojien [14], about 90,000 words among about 200,000 headwords are two-character compounds. So far, researches on two-character compounds in Japanese language...
have been concentrated mostly on morphological structures \cite{15, 16} and cognitive processes \cite{17, 18}. However, studies of the two-character compounds in Japanese language based on the network science seem to be insufficient. In the present paper, we report analysis results of networks of two-character compounds in Japanese language.

## 2 Method

First, we extracted networks of two-character compounds from the following Japanese-language dictionaries: Kojien, Iwanami Kokugo Jiten, Sanseido Kokugo Jiten, and Mitsumura Kokugo Gakushu Jiten \cite{14}. It is noted that Kojien, Iwanami, and Sanseido are standard dictionaries, but Mitsumura is a dictionary for students of elementary and junior high school. We picked out two-character compounds from the headwords of each dictionary.

In the network of two-character compounds, each Chinese character corresponds to a node, and each two-character compound formed by connecting two nodes is regarded as an edge. Each edge have a direction from an upper character to a lower character. Thus, this network is naturally viewed as a directed network with multiple edges and self loops. The direction of edges in the network deeply relates to lexical structure and meaning of two-character compounds. The multiplicity of edges represents the following two aspects: (i) some two-character compounds have two or more readings, and (ii) some compounds become other existing compounds when the upper and lower characters are inverted. A part of this network is depicted in Fig. 1.

In the networks we obtained, all nodes are not connective, and whole network is made up of 169 (Kojien), 152 (Iwanami), 142 (Sanseido), and 8 (Mitsumura) clusters. In the following analysis, we consider the maximal cluster in the network of each dictionary (more than 90% of nodes belong to the maximal cluster). Since essential features of the networks can be described even without the edge direction and multiplicity and self loops, we focus on the undirected and unweighted networks.

## 3 Results

Fundamental results obtained from each dictionary are summarized in Table 1. For instance, in the case of Kojien, a pair of two nodes is about three steps distant on average, and at most ten steps distant (see $\ell$ and $D$ in this Table). Clustering coefficient $C$ of each network is about 20 times greater than that of a random network of the same size in nodes and edges $C_{\text{rand}}$. Therefore, networks of two-character compounds have short path length and high clustering, as in many real networks \cite{19}. It is found that the degree distributions of the three networks (shown in Fig. 2 (a)-(c)) display power law

$$ p(k) \propto k^{-\gamma}, $$

where $p(k)$ denotes a fraction of nodes having degree $k$. Values of $\gamma$ are nearly 1 for these three dictionaries as shown in Table 1. However, as shown in Fig. 2 (d), the degree distribution of
Mitsumura does not exhibit clear power-law property.

4 Restricted network formed by Chinese characters for common use

In this section, we discuss the reason why the degree distribution of Mitsumura does not exhibit power law (see Fig. 2 (d) for reference). There are 1,945 Chinese characters designated for common use, which are called joyo-kanji in Japanese, selected by the Ministry of Education, Science and Culture of Japan in 1981. We call them ‘common-use characters’ heareafter. The common-use characters are taught during elementary and junior high school in Japan, and most Chinese characters used in Japan are the common-use characters. Moreover, Chinese characters except the common-use characters are not permitted to use in legal documents. We next consider a network constructed only by the common-use characters. It is noted that this network forms a subclass of the original network.

Fundamental results of the network restricted to the common-use characters are summarized in Table 2. For the first three dictionaries in Table 2, mean path lengths are small, and clustering coefficients are large, compared to those presented in Table 1. On the other hand, the properties of the network of Mitsumura in Table 2 is the same as those in Table 1. This reflects that two-character compounds listed in Mitsumura are all constructed from the common-use characters (recall that this dictionary is for students of elementary school and junior high school). As shown in Fig. 3, it is found that the degree distributions of the networks of the common-use characters do not show power-law behavior in the four dictionaries. These degree distributions share the features that there are plateaus in the range of small $k$ ($k \lesssim 10$) and decay in large $k$ ($k \gtrsim 10$).

5 Invasion model for selecting the common-use characters

The property of the degree distributions of the restricted networks shown above is considered to be caused by a selection process of the common-use characters. For this process, we propose a stochastic model on the ‘real’ maximal network of each dictionary. First, we assume that each node in the network has two states; invaded or uninvaded, and that all nodes are initially uninvaded. Then, one node is chosen randomly from the network and is turned into invaded. At each time step, one node $v_i$ is chosen with a probability $p_i$ from all uninvaded nodes $\{v_1, v_2, \ldots, v_n\}$ connecting to invaded nodes. The probability $p_i$ is assumed to be given by

$$p_i = \frac{k_i^\alpha}{\sum_{j=1}^{n} k_j^\alpha} \quad (i = 1, \ldots, n),$$

(1)
where $k_j$ represents a degree of a node $v_j$ and $\alpha$ is a constant, which is determined below. It is noted that the case $\alpha = 0$ corresponds to random growth, that is, all $v_i$ have equal probability of invasion, and that the case $\alpha > 0$ corresponds to ‘preferential’ growth, that is, a node of larger degree are invaded more easily [9, 20]. The invasion process is schematically shown in Fig. 4. In this model, invaded nodes are regarded as the common-use characters. The value of $\alpha$ should be positive, since the common-use characters tend to have large degrees. Thus, it can be said that this model is a preferential growth process of an invaded cluster on a network, and it is similar to invasion percolation [21] or Eden model [22].

The process of invasion was performed numerically until the number of invaded nodes amounted to the size of the network of the common-use characters in the dictionaries except Mitsumura. Then, we calculated $\langle k \rangle$ for the subnetwork of invaded nodes. To determine $\alpha$, we require that the average degree $\langle k \rangle$ of the subnetwork of invaded nodes becomes almost the same as that of real network of common-use characters. $\langle k \rangle$ as a function of $\alpha$ is depicted in Fig. 5 in the range $0 < \alpha < 2$. From this figure, it is suggested that $\alpha \approx 1.3$ is appropriate for the three dictionaries.

Numerical results are in good agreement with real networks as shown in Table 3. And Fig. 6 shows that degree distributions obtained from numerical result are also in good agreement with those obtained from real networks.

6 Discussion

Our analysis has proved that the network of two-character compounds has both small-world and scale-free properties. The possibility of emergence of the scale-free property seems to be associated with a fitness model [23]. In the fitness model, each node $v_i$ in a network has a fitness $x_i$ which is distributed independently and randomly with a given distribution function $\rho(x)$ (fitness generally represents some kind of “importance” or “sociability” of nodes). The edge between $v_i$ and $v_j$ is drawn with a probability given by $f(x_i, x_j)$ depending on the fitness of the nodes involved. And it is known that the fitness model can produce a power-law degree distribution.

For the network of two-character compounds, the frequency of use is uneven for each Chinese character: some characters are used quite frequently and some characters are used only in particular cases. And, it is naturally thought that creation of two-character compounds between Chinese characters used more widely arises more frequently. Hence, there may be an effect related to the fitness model so that the network of two-character compounds has the scale-free property (a fitness in this case relates to frequency of use).

We have also found that a network of the common-use characters is connective, and the average degree of the network is larger than that of the whole network. The invasion model proposed above is a simple method to assure connectivity and large degree of a resultant network. The model involves one parameter $\alpha$, and a growth process of invaded cluster depends on the value of $\alpha$. For positive $\alpha$, nodes of larger degree are assigned larger invasion probability.
according to Eq. (1). Hence most nodes of small degree don’t join a network generated from the model, and power-law behavior in degree distribution vanishes. Moreover, for appropriate value of $\alpha$, plateau emerges in a range of small $k$ in the degree distribution. It is proved that the value of $\alpha$ is nearly 1.3 for the three dictionaries in common, but we have not yet found clear explanation for this universality.

We have confirmed that the network characteristics (Table 1) and degree distributions (Figs. 2 and 3) are essentially the same when the edge direction and multiplicity and self loops are took into account. We think that further analysis with direction and multiplicity will provide more precise structures of the network of two-character compounds. However, such analysis may be rather linguistic or lexical. In fact, direction and multiplicity of edges are closely related to the individual meanings of characters and a formation principle of Japanese two-character compounds, which is classified into nine types from a grammatical point of view [24].

7 Conclusion

A network constructed by the two-character compounds in Japanese language has short path length and high clustering (Table 1). Also the network has power-law degree distribution (Fig. 2), but a subnetwork restricted to the common-use characters does not show power-law distribution (Fig. 3). Generation of the network of the common-use characters can be modeled by an invasion process in which the invasion probability of nodes with degree $k$ is proportional to $k^\alpha$ (see Eq. (1)). The exponent $\alpha$ is determined by consistency between real and numerical values of $\langle k \rangle$ (Fig. 5). It confirmed that the results obtained from the model are consistent with real networks quite well (Table 3).

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   (iii) Sanseido Kokugo Jiten (4th ed., Sanseido pu. co., Tokyo, 1992), and
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FIGURES & TABLES

Fig. 1 A part of the network extracted from Kojien: (a) original network, (b) network omitting direction, multiple edges, and self loops

Fig. 2 Degree distribution of the network of each dictionary: (a) Kojien, (b) Iwanami, (c) Sanseido, and (d) Mitsumura. In (a)-(c), the solid lines show guidelines of power-law behaviors.

Fig. 3 Degree distributions of networks of the common-use characters: (a) Kojien, (b) Iwanami, (c) Sanseido and (d) Mitsumura.

Fig. 4 An illustration of an invasion process on a network. A number on each node indicates a degree of the node, and a fractional number beside each node indicates an invasion probability ($\alpha = 1$) at each time step. The dashed and lines indicate edges of the whole network and generated subnetwork, respectively. Black nodes represent that they are invaded.

Fig. 5 Numerical results to determine the value of $\alpha$. The solid lines represent the average degree $\langle k \rangle$ obtained from the model as a function of $\alpha$ (averaging 50 samples), and dashed lines represent $\langle k \rangle$ shown in Table 2. The intersection of solid and dashed lines indicates $\alpha \approx (a) 1.29$ for Kojien, (b) 1.35 for Iwanami, and (c) 1.33 for Sanseido.

Fig. 6 Degree distributions of real common-use characters corresponding to (a1) Kojien, (b1) Iwanami, and (c1) Sanseido, and ones obtained from numerical results corresponding to (a2) Kojien, (b2) Iwanami, and (c2) Sanseido. (a1), (b1), and (c1) are identical to Fig. 3(a)-(c).

Table 1 The characteristics of the maximal cluster in a network of two-character compounds. $\langle k \rangle$, $\ell$, $D$, and $C$ denote average degree, mean path length, diameter, and clustering coefficient, respectively. $C_{\text{rand}}$ represents the averaged clustering coefficient of the 50 random networks of the same size in nodes and edges.

Table 2 The characteristics of the network of common-use characters.

Table 3 Comparison between real networks of common-use characters and numerical results ($\alpha = 1.3$). Numerical results are obtained by averaging 50 samples.
Figure 1: K. Yamamoto and Y. Yamazaki
Figure 2: K. Yamamoto and Y. Yamazaki
Figure 3: K. Yamamoto and Y. Yamazaki
Figure 5: K. Yamamoto and Y. Yamazaki
Figure 6: K. Yamamoto and Y. Yamazaki
Table 1: K. Yamamoto and Y. Yamazaki

| Dictionary   | Nodes | Edges   | $\langle k \rangle$ | $\ell$ | $D$   | $C$   | $C_{rand}$ | $\gamma$ |
|--------------|-------|---------|---------------------|-------|-------|-------|------------|---------|
| Kojien       | 5458  | 74617   | 27.3                | 3.14  | 10    | 0.138 | 0.00501    | 1.04    |
| Iwanami      | 3904  | 32150   | 16.5                | 3.31  | 10    | 0.085 | 0.00424    | 1.04    |
| Sanseido     | 3444  | 28358   | 16.5                | 3.32  | 9     | 0.086 | 0.00483    | 1.05    |
| Mitsumura    | 1799  | 9054    | 10.1                | 3.42  | 8     | 0.059 | 0.00255    | —       |
| dictionary  | Nodes | Edges | $\langle k \rangle$ | $\ell$ | $D$ | $C$ |
|-------------|-------|-------|------------------|------|----|-----|
| Kojien      | 1940  | 54181 | 55.9             | 2.32 | 5  | 0.172|
| Iwanami     | 1933  | 26419 | 27.3             | 2.67 | 6  | 0.111|
| Sanseido    | 1921  | 24726 | 25.7             | 2.73 | 7  | 0.114|
| Mitsumura   | 1799  | 9054  | 10.1             | 3.42 | 8  | 0.059|
Table 3: K. Yamamoto and Y. Yamazaki

| dictionary | Real networks |  | Numerical results |  |  |
|------------|---------------|---|-------------------|---|---|
|            | $\langle k \rangle$ | $\ell$ | $C$ | $\langle k \rangle$ | $\ell$ | $C$ |
| Kojien     | 55.9          | 2.32 | 0.172            | 56.0 ± 0.8 | 2.32 ± 0.01 | 0.175 ± 0.004 |
| Iwanami    | 27.3          | 2.67 | 0.111            | 27.2 ± 0.2 | 2.68 ± 0.01 | 0.109 ± 0.005 |
| Sanseido   | 25.7          | 2.73 | 0.114            | 25.7 ± 0.2 | 2.73 ± 0.02 | 0.109 ± 0.004 |