Modeling Categorization Dynamics through Conversation by Constructive Approach

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Abstract. Categorization dynamics as the clustering of words in word relation is studied by a constructive approach which is suited to inquire evolutionary linguistics with dynamical view on language. Word meaning is represented by relationship among words. Tthe relationship should be derived from usage of language. Being founded on this usage-based view, we define an algorithm to evaluate word relationship. Using the algorithm, cluster structure and its dynamics of words are shown in a model with communicating artificial agents. The relevance of clustering with linguistic categorization is discussed.

1 Dynamical View on Language

There are two ways of viewing language: structurally and dynamically. The structural view is a static one in which language structure, for example, syntax, dictionaries, or pragmatic rules, offers idealized approaches to language. The alternative view is dynamic. It concentrates on the actual use of language rather than abstract notions of how language ought to be. It is possible to better understand the value of the second approach by thinking of metaphor. Metaphoricalexpressions are creative and dynamic precisely because they can "bend" or "break" the rules of conventionally structured language. By producing or understanding metaphorical expressions, especially creative or unique metaphors, our internal models should change. We can not say valid or not valid for such creative expressions, since the expressions are so novel that it is not valid for a conventional language structure. We should consider whether the expressions are to be accepted or not. If we accept them, our internal structure changes and language structure might also come to be modified. In the dynamical view, the whole system of such dynamical processes is considered as 'language.'

Constructive approaches are highly advantageous to understanding complex systems [4]. These approaches are also useful for studying evolutionary linguistics [7]. In contrast to conventional linguistics which attempts to describe various language phenomena, in the constructive approach the emergence of global order as language-like behavior is modeled through interaction among individuals. However, not only emergence but also the dynamics of global order should be observed in constructive models, since language is indeed an ever-changing system.

Perhaps the internal dynamics of individuals should be taken into consideration to study evolutionary language system so as for individuals to change their internal states and relationship to others and circumstances.

2 Modeling – Word Relationship and Conversation

We have proposed *usage-based viewpoint* on meaning [2] which have claimed that meanings of words should be discussed in terms of how language is used [9]. Interrelationship among words can be employed as a representation of meanings of words to some extent. This point of view implies that relationship of one word to other words should be derived from analyzing the usage of the word in the language, not entirely from its indication or reference. Moreover, a word in a sentence is understood from not only relation with only entities mentioned by the sentence but position in the whole system of language.

Based on this viewpoint, we discuss dynamics of categorization by observing how the relationship among words changes through conversations. Building relationship in use of language is a dynamical process performed by language users. We call this process *sense-making* process [1] to emphasize its subjective nature. The sense-making process is modeled by positioning a word in the relationship among all words.

The algorithm to evaluate relationship between words is basically attributed to Karov and Edelman's work [5] with two revisions. The one is to calculate relationship dynamically in the course of conversation, since what interests us is not in the final form of category but in the dynamics of categorization. The other is to consider 'texts' on higher level than sentences[1]. A text is a stream of sentences uttered and accepted. The relationship between words is defined by the linear combination of the terms of usage-similarity and appearance-similarity using a coefficient α^w as[2]

$$R(w_i, w_j) = \alpha^w(\text{usage-similarity}) + (1 - \alpha^w)(\text{appearance-similarity}) \ .$$

The first term is designed to calculate usage similarity of words in sentences by considering the syntagmatic relationships between words, i.e. words used in a sentence are in strong relationship. Since this algorithm is applied iteratively for each sentence in texts, words used not in a sentence but at the same position in different sentences grow their relationship. In other words, this algorithm is able to capture the paradigmatic relationship from the syntagmatic one.

The second term seizes the similarity among patterns of appearance of words in texts. Words with resemblant patterns of appearance among texts, e.g., words used much often in particular texts but not so in other texts, raise their relationship. Conversely, words with different patterns of appearance weaken their relationship. This is realized by calculating the correlation of appearance in texts.

[1] A text is a set of sentences. In our paper, this is applied to a conversation.
[2] As space is limited, for the detail of the algorithm, see [3].

We model a simple conversation process between agents having word relation matrices as their internal structures. Here, we focus on dynamical changes of internal structures of agents through exchanging sentences, the simplest act of using language. A conversation between agents starts with uttering a sentence about a topic displayed to the agents. After the beginning of the conversation, each sentence is not restricted to the topic but there is some relevance with the previous sentence. In this model, to express this relevance, at least one word in the accepted sentence should be used in a reply sentence.

The procedure of conversation in a text is as follows:
1. A speaker agent produces a sentence about a topic.
2. The sentence is modified according to the creativity rate, c, and then uttered to a hearer agent.
3. The speaker's word relation matrix is updated in terms of the uttered sentence.
4. The hearer accepts the uttered sentence if there are less than two unknown words in the sentence[3]. If the sentence is not accepted, the speaker turns to another topic. (go to 1.)
5. The hearer's word relation matrix is updated in terms of the accepted sentence. If there is an unknown word, the matrix is expanded to incorporate the new word.
6. To reply to the utterance, the role of speaker and hearer are exchanged between them. (go to 1.)

When the number of accepted sentences or that of rejected sentences in a text reach some values, the text ends up. Then another pair of agents and a topic are selected for a new text.

3 Summary of Simulation Results

In one conversation, two agents from five are randomly selected as a speaker and a hearer. Sentences are produced artificially by agents by arranging words in which 5 different characters are combined[4]. The number of topics to be displayed to agents is 10. The maximum of accepted sentences in a text is 100 and that of rejected sentences is 5. The parameters are $\alpha^w = 0.4$, $c = 0.1$.

The followings are the major results:

1. Agents develop cluster structure in their own word relation matrices. We observe two characteristic types of clusters. One is flat type in which words have strong relationship with each other. The other is gradual type in which word relationships change gradually. As a result of development, these two types of clusters exist in combination.

2. Relationship among words drastically changes when a new word is used or a word is used in an unusual way. For example, at the 21st text in Fig.1(a) most words with strong relation with a word in new usage weaken their relation value and vice versa.

[3] Note that the criterion for acceptance of uttered sentence by the hearer lays down the limitation of ability to make sense for new words.
[4] The number of words and that of sentences are in principle infinity.

3. The structure of clusters has stability and adaptability. The change of position of words in cluster structure is examplified in Fig.1(b). The words in a new usage, linked with a dashed arrow, moves its belonging cluster. The other words move so coherently in each cluster that the whole structure of clusters is not modified very much.

4. Structure common to agents develops in the course of conversations.

5. Agents also develop structure peculiar to individuals, because they go through diversified experiences of conversations.

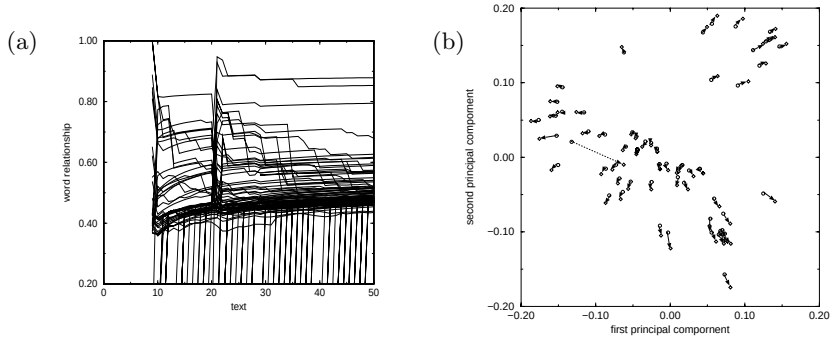

Fig. 1. (a) Transition of word relationship. The x and y axes are the number of texts and the relationship of all words with a word in an agent's word relation matrix, respectively. (b) Dynamics of cluster structure caused by the rapid change shown in (a). This is a scattered diagram from principal component analysis of matrices.

4 Discussions

The clustering can be regarded as categorization through conversations, since words in a cluster have stronger relation with each other and weaker relation with words outside the cluster. Typical clusters are a combination of two types of clusters, flat and gradual, that is, a flat center with gradual expansion into the peripheral. The cluster structure shares some characteristics with the prototype category [6, 8].

In the traditional notion of category, the membership of a category is thought to be defined rigidly like the set notion. In the prototype category theory, in contrast, the membership is matter of gradient and the boundary of a category is fuzzy. The category of liquid containers provides an example. Bottles and glasses are the typical members of the category. Glasses are similar to bowls, bowls are to soup plates, and soup plates are to flat dishes. Although neighboring members are fairly similar, the last one may not be the member of the category, but the boundary which defines the membership of the category is unclear. Another important feature of prototype categories is stability and adaptability with which languages should equip themselves to establish communication and

to be flexible about changes. Prototype category and our cluster structure are akin in these traits[5].

Agents develop both commonality and individuality. The structure common to agents implies the emergence of a social system, in which some words are used in the same way by most agents. The words acquire, in the speculative view, virtual references in the society[6]. For a developmental enquiry, we should study how word relationship which reflects relation among prepared entities changes or expands with communication.

The present algorithm shows not a simple convergence but drastic turnovers, which are usually brought by new combinations of words. The turnover behavior locally restructures words in clusters. Such new combinations of words is like metaphorical expressions which often tie different semantic domains by using words from the separated domains in one sentence. And such metaphorical expressions, if they are totally impressive, might modify our internal models, or world view, dramatically. Therefore, it is important for dynamics of linguistic categorization not only to develop clusters but to modify the clusters by a small impact. This is also important for maintaining the dynamics at the global level.

The coefficient parameter α^w controls nonlinearity of the present system. Although the results reported here are seen in the broad area of α^w, the system is likely to fall into fixed and uniform structure at the too large value of α^w. If the creativity rate c is too large, the system has too strong randomness for us to find any significant structure in word relation matrices and their dynamics.

References

1. M. Fukaya and S. Tanaka. *Kotoba no ⟨Imiduke-ron⟩ (A Theory of "Sence Making" of Language)* [in Japanese]. Kinokuniya Shoten, Tokyo, 1996.
2. T. Hashimoto. Usage-based structuralization of relationships between words. In P. Husbands and I. Harvey, editors, *Fourth European Conference on Artificial Life*, pages 483–492. MIT Press, Cambridge, MA, 1997.
3. T. Hashimoto. Dynamics of internal and global structure through linguistic interactions. In Conte Sichman and Gilbert, editors, *Multi-Agent Systems and Agent-Based Simulation*, pages 124–139. Springer-Verlag, Berlin, 1998.
4. K. Kaneko and I. Tsuda. Constructive complexity and artificial reality: an introduction. *Physica*, D75:1–10, 1994.
5. Y. Karov and S. Edelman. Similarity-based word sense disambiguation. *Computational Linguistics*, 24:41–59, 1998.
6. G. Lakoff. *Women, Fire, and Dangerous Things*. The University of Chicago Press, Chicago, 1987.
7. L. Steels. The synthetic modeling of language origin. *Evolution of Communication*, 1(1):1–34, 1997.
8. J. R. Taylor. *Linguistic Categorization – Prototypes in Linguistic Theory*. Oxford University Press, Oxford, 1995.
9. L. Wittgenstein. *Philosophische Untersuchungen*. Basil Blackwell, 1953.

[5] Prototype category has some other attributes[8].

[6] Some abstract notions might be created in our society and internalized in using language.