

Similarity between Words Computed by Spreading Activation on an English Dictionary

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Abstract

This paper proposes a method for measuring semantic similarity between words as a new tool for text analysis. The similarity is measured on a semantic network constructed systematically from a subset of the English dictionary, LDOCE (*Longman Dictionary of Contemporary English*). Spreading activation on the network can directly compute the similarity between any two words in the *Longman Defining Vocabulary*, and indirectly the similarity of all the other words in LDOCE. The similarity represents the strength of lexical cohesion or semantic relation, and also provides valuable information about similarity and coherence of texts.

1 Introduction

A text is not just a sequence of words, but it also has coherent structure. The meaning of each word in a text depends on the structure of the text. Recognizing the structure of text is an essential task in text understanding.[Grosz and Sidner, 1986]

One of the valuable indicators of the structure of text is lexical cohesion.[Halliday and Hasan, 1976] Lexical cohesion is the relationship between words, classified as follows:

1. Reiteration:
Molly likes *cats*. She keeps a *cat*.
2. Semantic relation:
 - a. Desmond saw a *cat*. It was Molly's *pet*.
 - b. Molly goes to the *north*. Not *east*.
 - c. Desmond goes to a *theatre*. He likes *films*.

Reiteration of words is easy to capture by morphological analysis. Semantic relation between words, which is the focus of this paper, is hard to recognize by computers.

We consider lexical cohesion as semantic similarity between words. Similarity is computed by spreading activation (or association) [Waltz and Pollack, 1985] on a semantic network constructed systematically from an English dictionary. Whereas it is edited by some lexicographers, a dictionary is a set of associative relation shared by the people in a linguistic community.

The similarity between words is a mapping $\sigma: L \times L \rightarrow [0, 1]$, where L is a set of words (or lexicon). The following examples suggest the feature of the similarity:

$$\begin{aligned}\sigma(\text{cat}, \text{pet}) &= 0.133722 \quad (\text{similar}), \\ \sigma(\text{cat}, \text{mat}) &= 0.002692 \quad (\text{dissimilar}).\end{aligned}$$

The value of $\sigma(w, w')$ increases with strength of semantic relation between w and w' .

The following section examines related work in order to clarify the nature of the semantic similarity. Section 3 describes how the semantic network is systematically constructed from the English dictionary. Section 4 explains how to measure the similarity by spreading activation on the semantic network. Section 5 shows applications of the similarity measure — computing similarity between texts, and measuring coherence of a text. Section 6 discusses the theoretical aspects of the similarity.

2 Related Work on Measuring Similarity

Words in a language are organized by two kinds of relationship. One is a syntagmatic relation: how the words are arranged in sequential texts. The other is a

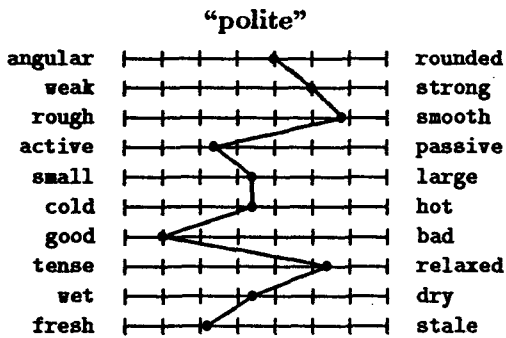


Figure 1. A psycholinguistic measurement (semantic differential [Osgood, 1952]).

paradigmatic relation: how the words are associated with each other. Similarity between words can be defined by either a syntagmatic or a paradigmatic relation.

Syntagmatic similarity is based on co-occurrence data extracted from corpora [Church and Hanks, 1990], definitions in dictionaries [Wilks *et al.*, 1989], and so on. Paradigmatic similarity is based on association data extracted from thesauri [Morris and Hirst, 1991], psychological experiments [Osgood, 1952], and so on.

This paper concentrates on paradigmatic similarity, because a paradigmatic relation can be established both inside a sentence and across sentence boundaries, while syntagmatic relations can be seen mainly inside a sentence — like syntax deals with sentence structure. The rest of this section focuses on two related works on measuring paradigmatic similarity — a psycholinguistic approach and a thesaurus-based approach.

2.1 A Psycholinguistic Approach

Psycholinguists have been proposed methods for measuring similarity. One of the pioneering works is ‘semantic differential’ [Osgood, 1952] which analyses meaning of words into a range of different dimensions with the opposed adjectives at both ends (see Figure 1), and locates the words in the semantic space.

Recent works on knowledge representation are somewhat related to Osgood’s semantic differential. Most of them describe meaning of words using special symbols like microfeatures [Waltz and Pollack, 1985; Hendler, 1989] that correspond to the semantic dimensions.

However, the following problems arise from the semantic differential procedure as measurement of meaning. The procedure is not based on the denotative meaning of a word, but only on the connotative emotions attached to the word; it is difficult to choose the relevant dimensions, i.e. the dimensions required for the sufficient semantic space.

2.2 A Thesaurus-based Approach

Morris and Hirst [1991] used Roget’s thesaurus as knowledge base for determining whether or not two words are semantically related. For example, the semantic relation of truck/car and drive/car are captured in the following way:

1. $\text{truck} \in \text{vehicle} \ni \text{car}$
(both are included in the *vehicle* class),
2. $\text{drive} \in \text{journey} \rightarrow \text{vehicle} \ni \text{car}$
(*journey* refers to *vehicle*).

This method can capture almost all types of semantic relations (except emotional and situational relation), such as paraphrasing by superordinate (ex. cat/pet), systematic relation (ex. north/east), and non-systematic relation (ex. theatre/film).

However, thesauri provide neither information about semantic difference between words juxtaposed in a category, nor about strength of the semantic relation between words — both are to be dealt in this paper. The reason is that thesauri are designed to help writers find relevant words, not to provide the meaning of words.

3 Paradigme: A Field for Measuring Similarity

We analyse word meaning in terms of the semantic space defined by a semantic network, called *Paradigme*. *Paradigme* is systematically constructed from *Glossème*, a subset of an English dictionary.

3.1 Glossème — A Closed Subsystem of English

A dictionary is a closed paraphrasing system of natural language. Each of its headwords is defined by a phrase which is composed of the headwords and their derivations. A dictionary, viewed as a whole, looks like a tangled network of words.

We adopted *Longman Dictionary of Contemporary English* (LDOCE) [1987] as such a closed system of English. LDOCE has a unique feature that each of its 56,000 headwords is defined by using the words in *Longman Defining Vocabulary* (hereafter, LDV) and their derivations. LDV consists of 2,851 words (as the headwords in LDOCE) based on the survey of restricted vocabulary [West, 1953].

We made a reduced version of LDOCE, called *Glossème*. *Glossème* has every entry of LDOCE whose headword is included in LDV. Thus, LDV is defined by *Glossème*, and *Glossème* is composed of LDV. *Glossème* is a closed subsystem of English.

Glossème has 2,851 entries that consist of 101,861 words (35.73 words/entry on the average). An item of *Glossème* has a *headword*, a *word-class*, and one or more *units* corresponding to numbered definitions in the entry of LDOCE. Each unit has one *head-part* and several *det-parts*. The head-part is the first phrase in the definition, which describes the broader

<p>red¹ /red/ adj-dd- 1 of the colour of blood or fire: <i>a red rose/dress</i> <i>We painted the door red.</i> — see also like a red rag to a bull (RAG¹) 2 (of human hair) of a bright brownish orange or copper colour 3 (of the human skin) pink, usu. for a short time: <i>I turned red with embarrassment/anger.</i> <i>The child's eye</i> (= the skin round the eyes) <i>were red from crying.</i> 4 (of wine) of a dark pink to dark purple colour — ~ness n [U]</p>	<pre>(red adj ; headword, word-class ((of the colour) ; unit 1 -- head-part (of blood or fire)) ; det-part ((of a bright brownish orange or copper colour) (of human hair)) (pink ; unit 3 -- head-part (usu for a short time) ; det-part 1 (of the human skin)) ; det-part 2 ((of a dark pink to dark purple colour) (of wine)))</pre>
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Figure 2. A sample entry of LDOCE and a corresponding entry of *Glossème* (in S-expression).

```
(red_1 (adj) 0.000000 ;; headword, word-class, and activity-value
;; referant
(+ ;; subreferant 1
(0.333333 ;; weight of subreferant 1
(* (0.001594 of_1) (0.001733 the_1) (0.001733 the_2) (0.042108 colour_1)
(0.042108 colour_2) (0.000797 of_1) (0.539281 blood_1) (0.000529 or_1)
(0.185058 fire_1) (0.185058 fire_2) ))
;; subreferant 2
(0.277778
(* (0.000278 of_1) (0.000196 a_1) (0.030997 bright_1) (0.065587 brown_1)
(0.466411 orange_1) (0.000184 or_1) (0.385443 copper_1) (0.007330 colour_1)
(0.007330 colour_2) (0.000139 of_1) (0.009868 human_1) (0.009868 human_2)
(0.016372 hair_1) ))
;; subreferant 3
(0.222222
(* (0.410692 pink_1) (0.410692 pink_2) (0.003210 for_1) (0.000386 a_1)
(0.028846 short_1) (0.006263 time_1) (0.000547 of_1) (0.000595 the_1)
(0.000595 the_2) (0.038896 human_1) (0.038896 human_2) (0.060383 skin_1) ))
;; subreferant 4
(0.166667
(* (0.000328 of_1) (0.000232 a_1) (0.028368 dark_1) (0.028368 dark_2)
(0.123290 pink_1) (0.123290 pink_2) (0.000273 to_1) (0.000273 to_2)
(0.000273 to_3) (0.028368 dark_1) (0.028368 dark_2) (0.141273 purple_1)
(0.141273 purple_2) (0.008673 colour_1) (0.008673 colour_2) (0.000164 of_1)
(0.338512 wine_1) )))
;; refere
(* (0.031058 apple_1) (0.029261 blood_1) (0.008678 colour_1) (0.009256 comb_1)
(0.029140 copper_1) (0.009537 diamond_1) (0.003015 fire_1) (0.073762 flame_1)
(0.005464 fox_1) (0.005152 heart_1) (0.098349 lake_2) (0.007025 lip_1)
(0.029140 orange_1) (0.007714 pepper_1) (0.196698 pink_1) (0.012294 pink_2)
(0.098349 pink_2) (0.018733 purple_2) (0.028100 purple_2) (0.098349 red_2)
(0.196698 red_2) (0.004230 signal_1) ))
```

Figure 3. A sample node of *Paradigme* (in S-expression).

meaning of the headword. The det-parts restrict the meaning of the head-part. (See Figure 2.)

3.2 Paradigme — A Semantic Network

We then translated *Glossème* into a semantic network *Paradigme*. Each entry in *Glossème* is mapped onto a node in *Paradigme*. *Paradigme* has 2,851 nodes and 295,914 unnamed links between the nodes (103.79 links/node on the average). Figure 3 shows a sample node *red_1*. Each node consists of a *headword*, a *word-class*, an *activity-value*, and two sets of links: a *référent* and a *référé*.

A *référent* of a node consists of several *subréférents* correspond to the units of *Glossème*. As shown in Figure 2 and 3, a morphological analysis maps the word *brownish* in the second unit onto a link to the node *brown_1*, and the word *colour* onto two links

to *colour_1* (adjective) and *colour_2* (noun).

A *référé* of a node *p* records the nodes referring to *p*. For example, the *référé* of *red_1* is a set of links to nodes (ex. *apple_1*) that have a link to *red_1* in their *référents*. The *référé* provides information about the *extension* of *red_1*, not the *intension* shown in the *référent*.

Each link has *thickness* t_k , which is computed from the frequency of the word w_k in *Glossème* and other information, and normalized as $\sum t_k = 1$ in each *subréférent* or *référé*. Each *subréférent* also has *thickness* (for example, 0.333333 in the first *subréférent* of *red_1*), which is computed by the order of the units which represents significance of the definitions. Appendix A describes the structure of *Paradigme* in detail.

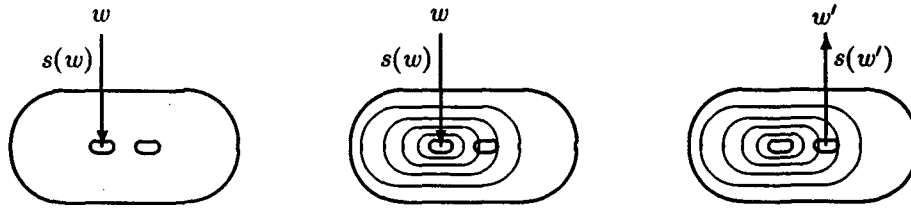


Figure 4. Process of measuring the similarity $\sigma(w, w')$ on *Paradigme*.
 (1) Start activating w . (2) Produce an activated pattern. (3) Observe activity of w' .

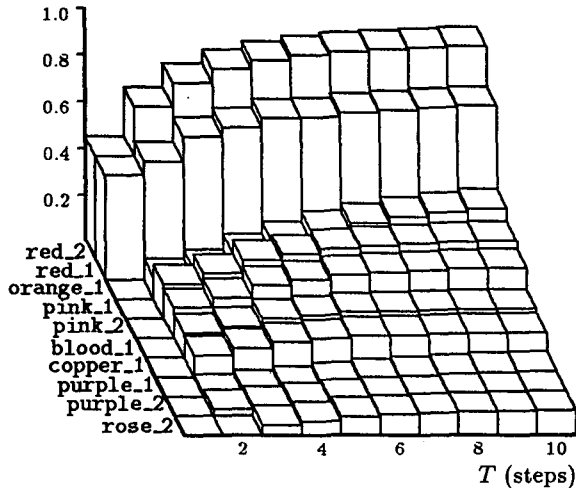


Figure 5. An activated pattern produced from red (changing of activity values of 10 nodes holding highest activity at $T=10$).

4 Computing Similarity between Words

Similarity between words is computed by spreading activation on *Paradigme*. Each of its nodes can hold activity, and it moves through the links. Each node computes its activity value $v_i(T+1)$ at time $T+1$ as follows:

$$v(T+1) = \phi(R_i(T), R'_i(T), e_i(T)),$$

where $R_i(T)$ and $R'_i(T)$ are the sum of weighted activity (at time T) of the nodes referred in the référent and référé respectively. And, $e_i(T)$ is activity given from outside (at time T); to 'activate a node' is to let $e_i(T) > 0$. The output function ϕ sums up three activity values in appropriate proportion and limits the output value to $[0,1]$. Appendix B gives the details of the spreading activation.

4.1 Measuring Similarity

Activating a node for a certain period of time causes the activity to spread over *Paradigme* and produce an activated pattern on it. The activated pattern approximately gets equilibrium after 10 steps, whereas

it will never reach the actual equilibrium. The pattern thus produced represents the meaning of the node or of the words related to the node by morphological analysis¹.

The activated pattern, produced from a word w , suggests similarity between w and any headword in LDV. The similarity $\sigma(w, w') \in [0, 1]$ is computed in the following way. (See also Figure 4.)

1. Reset activity of all nodes in *Paradigme*.
2. Activate w with strength $s(w)$ for 10 steps, where $s(w)$ is significance of the word w . Then, an activated pattern $P(w)$ is produced on *Paradigme*.
3. Observe $a(P(w), w')$ — an activity value of the node w' in $P(w)$. Then, $\sigma(w, w')$ is $s(w') \cdot a(P(w), w')$.

The word significance $s(w) \in [0, 1]$ is defined as the normalized information of the word w in the corpus [West, 1953]. For example, the word **red** appears 2,308 times in the 5,487,056-word corpus, and the word **and** appears 106,064 times. So, $s(\text{red})$ and $s(\text{and})$ are computed as follows:

$$s(\text{red}) = \frac{-\log(2308/5487056)}{-\log(1/5487056)} = 0.500955,$$

$$s(\text{and}) = \frac{-\log(106064/5487056)}{-\log(1/5487056)} = 0.254294.$$

We estimated the significance of the words excluded from the word list [West, 1953] at the average significance of their word classes. This interpolation virtually enlarged West's 5,000,000-word corpus.

For example, let us consider the similarity between **red** and **orange**. First, we produce an activated pattern $P(\text{red})$ on *Paradigme*. (See Figure 5.) In this case, both of the nodes **red_1** (adjective) and **red_2** (noun) are activated with strength $s(\text{red}) = 0.500955$. Next, we compute $s(\text{orange}) = 0.676253$, and observe $a(P(\text{red}), \text{orange}) = 0.390774$. Then, the similarity between **red** and **orange** is obtained as follows:

$$\begin{aligned} \sigma(\text{red}, \text{orange}) &= 0.676253 \cdot 0.390774 \\ &= 0.264262. \end{aligned}$$

¹The morphological analysis maps all words derived by 48 affixes in LDV onto their root forms (i.e. headwords of LDOCE).

4.2 Examples of Similarity between Words

The procedure described above can compute the similarity $\sigma(w, w')$ between any two words w, w' in LDV and their derivations. Computer programs of this procedure — spreading activation (in C), morphological analysis and others (in Common Lisp) — can compute $\sigma(w, w')$ within 2.5 seconds on a workstation (SPARCstation 2).

The similarity σ between words works as an indicator of the lexical cohesion. The following examples illustrate that σ increases with the strength of semantic relation:

$\sigma(\text{wine}, \text{alcohol})$	=	0.118078 ,
$\sigma(\text{wine}, \text{line})$	=	0.002040 ,
$\sigma(\text{big}, \text{large})$	=	0.120587 ,
$\sigma(\text{clean}, \text{large})$	=	0.004943 ,
$\sigma(\text{buy}, \text{sell})$	=	0.135686 ,
$\sigma(\text{buy}, \text{walk})$	=	0.007993 .

The similarity σ also increases with the co-occurrence tendency of words, for example:

$\sigma(\text{waiter}, \text{restaurant})$	=	0.175699 ,
$\sigma(\text{computer}, \text{restaurant})$	=	0.003268 ,
$\sigma(\text{red}, \text{blood})$	=	0.111443 ,
$\sigma(\text{green}, \text{blood})$	=	0.002268 ,
$\sigma(\text{dig}, \text{spade})$	=	0.116200 ,
$\sigma(\text{fly}, \text{spade})$	=	0.003431 .

Note that $\sigma(w, w')$ has direction (from w to w'), so that $\sigma(w, w')$ may not be equal to $\sigma(w', w)$:

$\sigma(\text{films}, \text{theatre})$	=	0.178988 ,
$\sigma(\text{theatre}, \text{films})$	=	0.068927 .

Meaningful words should have higher similarity; meaningless words (especially, function words) should have lower similarity. The similarity $\sigma(w, w')$ increases with the significance $s(w)$ and $s(w')$ that represent meaningfulness of w and w' :

$\sigma(\text{north}, \text{east})$	=	0.100482 ,
$\sigma(\text{to}, \text{theatre})$	=	0.007259 ,
$\sigma(\text{films}, \text{of})$	=	0.005914 ,
$\sigma(\text{to}, \text{the})$	=	0.002240 .

Note that the reflective similarity $\sigma(w, w)$ also depends on the significance $s(w)$, so that $\sigma(w, w) \leq 1$:

$\sigma(\text{waiter}, \text{waiter})$	=	0.596803 ,
$\sigma(\text{of}, \text{of})$	=	0.045256 .

4.3 Similarity of Extra Words

The similarity of words in LDV and their derivations is measured directly on *Paradigme*; the similarity of extra words is measured indirectly on *Paradigme* by treating an extra word as a word list $W = \{w_1, \dots, w_n\}$ of its definition in LDOCE. (Note that each $w_i \in W$ is included in LDV or their derivations.)

The similarity between the word lists W, W' is defined as follows. (See also Figure 6.)

$$\sigma(W, W') = \psi \left(\sum_{w' \in W'} s(w') \cdot a(P(W), w') \right),$$

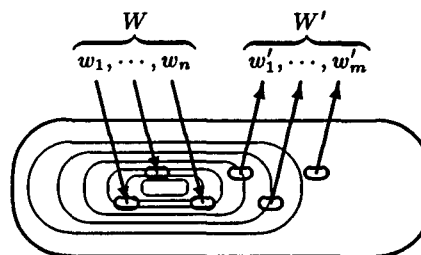


Figure 6. Measuring similarity of extra words as the similarity between word lists.

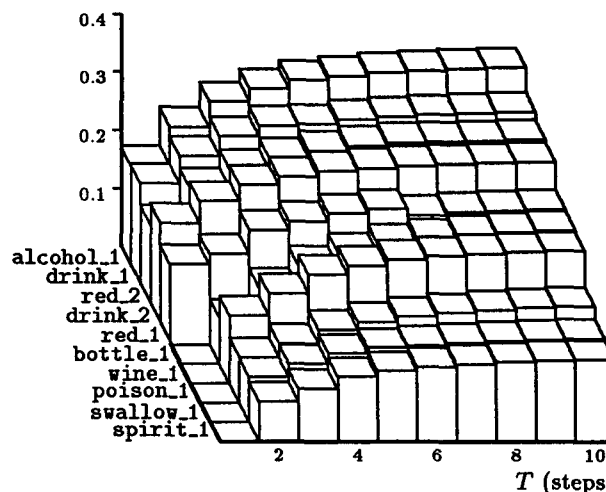


Figure 7. An activated pattern produced from the word list: {red, alcoholic, drink}.

where $P(W)$ is the activated pattern produced from W by activating each $w_i \in W$ with strength $s(w_i)^2 / \sum s(w_k)$ for 10 steps. And, ψ is an output function which limits the value to $[0, 1]$.

As shown in Figure 7, *bottle_1* and *wine_1* have high activity in the pattern produced from the phrase “red alcoholic drink”. So, we may say that the overlapped pattern implies “a bottle of wine”.

For example, the similarity between *linguistics* and *stylistics*, both are the extra words, is computed as follows:

$$\begin{aligned} \sigma(\text{linguistics}, \text{stylistics}) &= \sigma(\{\text{the, study, of, language, in,} \\ &\quad \text{general, and, of, particular,} \\ &\quad \text{languages, and, their, structure,} \\ &\quad \text{and, grammar, and, history}\}, \\ &\quad \{\text{the, study, of, style, in,} \\ &\quad \text{written, or, spoken, language}\}) \\ &= 0.140089 . \end{aligned}$$

Obviously, both $\sigma(W, w)$ and $\sigma(w, W)$, where W is an extra word and w is not, are also computable. Therefore, we can compute the similarity between any two headwords in LDOCE and their derivations.

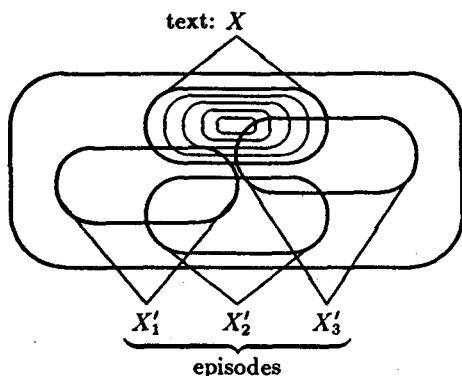


Figure 8. Episode association on *Paradigme* (recalling the most similar episode in memory).

5 Applications of the Similarity

This section shows the application of the similarity between words to text analysis — measuring similarity between texts, and measuring text coherence.

5.1 Measuring Similarity between Texts

Suppose a text is a word list without syntactic structure. Then, the similarity $\sigma(X, X')$ between two texts X, X' can be computed as the similarity of extra words described above.

The following examples suggest that the similarity between texts indicates the strength of coherence relation between them:

σ ("I have a hammer.", "Take some nails.")	= 0.100611 ,
σ ("I have a hammer.", "Take some apples.")	= 0.005295 ,
σ ("I have a pen.", "Where is ink?")	= 0.113140 ,
σ ("I have a pen.", "Where do you live?")	= 0.007676 .

It is worth noting that meaningless iteration of words (especially, of function words) has less influence on the text similarity:

σ ("It is a dog.", "That must be your dog.")	= 0.252536 ,
σ ("It is a dog.", "It is a log.")	= 0.053261 .

The text similarity provides a semantic space for text retrieval — to recall the most similar text in $\{X'_1, \dots, X'_n\}$ to the given text X . Once the activated pattern $P(X)$ of the text X is produced on *Paradigme*, we can compute and compare the similarity $\sigma(X, X'_1), \dots, \sigma(X, X'_n)$ immediately. (See Figure 8.)

5.2 Measuring Text Coherence

Let us consider the reflective similarity $\sigma(X, X)$ of a text X , and use the notation $c(X)$ for $\sigma(X, X)$. Then, $c(X)$ can be computed as follows:

$$c(X) = \psi \left(\sum_{w \in X} s(w) a(P(X), w) \right).$$

The activated pattern $P(X)$, as shown in Figure 7, represents the average meaning of $w_i \in X$. So, $c(X)$ represents cohesiveness of X — or semantic closeness of $w \in X$, or semantic compactness of X . (It is also closely related to *distortion* in clustering.)

The following examples suggest that $c(X)$ indicates the strength of coherence of X :

c ("She opened the world with her typewriter. Her work was typing. But She did not type quickly.")	= 0.502510 (coherent),
c ("Put on your clothes at once. I can not walk ten miles. There is no one here but me.")	= 0.250840 (incoherent).

However, a cohesive text can be incoherent; the following example shows cohesiveness of the incoherent text — three sentences randomly selected from LDOCE:

c ("I saw a lion. A lion belongs to the cat family. My family keeps a pet.")	= 0.560172 (incoherent, but cohesive).
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Thus, $c(X)$ can not capture all the aspects of text coherence. This is because $c(X)$ is based only on the lexical cohesion of the words in X .

6 Discussion

The structure of *Paradigme* represents the knowledge system of English, and an activated state produced on it represents word meaning. This section discusses the nature of the structure and states of *Paradigme*, and also the nature of the similarity computed on it.

6.1 Paradigme and Semantic Space

The set of all the possible activated patterns produced on *Paradigme* can be considered as a semantic space where each state is represented as a point. The semantic space is a 2,851-dimensional hypercube; each of its edges corresponds to a word in LDV.

LDV is selected according to the following information: the word frequency in written English, and the range of contexts in which each word appears. So, LDV has a potential for covering all the concepts commonly found in the world.

This implies the completeness of LDV as dimensions of the semantic space. Osgood's semantic differential procedure [1952] used 50 adjective dimensions; our semantic measurement uses 2,851 dimensions with completeness and objectivity.

Our method can be applied to construct a semantic network from an ordinary dictionary whose

defining vocabulary is not restricted. Such a network, however, is too large to spread activity over it. *Paradigme* is the small and complete network for measuring the similarity.

6.2 Connotation and Extension of Words

The proposed similarity is based only on the denotational and intensional definitions in the dictionary LDOCE. Lack of the connotational and extensional knowledge causes some unexpected results of measuring the similarity. For example, consider the following similarity:

$$\sigma(\text{tree}, \text{leaf}) = 0.008693.$$

This is due to the nature of the dictionary definitions — they only indicate sufficient conditions of the headword. For example, the definition of *tree* in LDOCE tells nothing about leaves:

tree *n* 1 a tall plant with a wooden trunk and branches, that lives for many years 2 a bush or other plant with a treelike form 3 a drawing with a branching form, esp. as used for showing family relationships

However, the definition is followed by pictures of leafy trees providing readers with connotational and extensional stereotypes of trees.

6.3 Paradigmatic and Syntagmatic Similarity

In the proposed method, the definitions in LDOCE are treated as word lists, though they are phrases with syntactic structures. Let us consider the following definition of *lift*:

lift *v* 1 to bring from a lower to a higher level; raise 2 (of movable parts) to be able to be lifted 3 ...

Anyone can imagine that something is moving upward. But, such a movement can not be represented in the activated pattern produced from the phrase. The meaning of a phrase, sentence, or text should be represented as pattern changing in time, though what we need is static and paradigmatic relation.

This paradox also arises in measuring the similarity between texts and the text coherence. As we have seen in Section 5, there is a difference between the similarity of texts and the similarity of word lists, and also between the coherence of a text and cohesiveness of a word list.

However, so far as the similarity between words is concerned, we assume that activated patterns on *Paradigme* will approximate the meaning of words, like a still picture can express a story.

7 Conclusion

We described measurement of semantic similarity between words. The similarity between words is computed by spreading activation on the semantic net-

work *Paradigme* which is systematically constructed from a subset of the English dictionary LDOCE. *Paradigme* can directly compute the similarity between any two words in LDV, and indirectly the similarity of all the other words in LDOCE.

The similarity between words provides a new method for analysing the structure of text. It can be applied to computing the similarity between texts, and measuring the cohesiveness of a text which suggests coherence of the text, as we have seen in Section 5. And, we are now applying it to text segmentation [Grosz and Sidner, 1986; Youmans, 1991], i.e. to capture the shifts of coherent scenes in a story.

In future research, we intend to deal with syntagmatic relations between words. Meaning of a text lies in the texture of paradigmatic and syntagmatic relations between words [Hjelmslev, 1943]. *Paradigme* provides the former dimension — an associative system of words — as a screen onto which the meaning of a word is projected like a still picture. The latter dimension — syntactic process — will be treated as a film projected dynamically onto *Paradigme*. This enables us to measure the similarity between texts as a syntactic process, not as word lists.

We regard *Paradigme* as a field for the interaction between text and episodes in memory — the interaction between what one is hearing or reading and what one knows [Schank, 1990]. The meaning of words, sentences, or even texts can be projected in a uniform way on *Paradigme*, as we have seen in Section 4 and 5. Similarly, we can project text and episodes, and recall the most relevant episode for interpretation of the text.

Appendix A. Structure of Paradigme — Mapping Glossème onto Paradigme

The semantic network *Paradigme* is systematically constructed from the small and closed English dictionary *Glossème*. Each entry of *Glossème* is mapped onto a node of *Paradigme* in the following way. (See also Figure 2 and 3.)

Step 1. For each entry G_i in *Glossème*, map each unit u_{ij} in G_i onto a subréférent s_{ij} of the corresponding node P_i in *Paradigme*. Each word $w_{ijn} \in u_{ij}$ is mapped onto a link or links in s_{ij} , in the following way:

1. Let t_n be the reciprocal of the number of appearance of w_{ijn} (as its root form) in *Glossème*.
2. If w_{ijn} is in a head-part, let t_n be doubled.
3. Find nodes $\{p_{n1}, p_{n2}, \dots\}$ corresponds to w_{ijn} (ex. *red* \rightarrow $\{\text{red}_1, \text{red}_2\}$). Then, divide t_n into $\{t_{n1}, t_{n2}, \dots\}$ in proportion to their frequency.
4. Add links l_{n1}, l_{n2}, \dots to s_{ij} , where l_{nm} is a link to the node p_{nm} with thickness t_{nm} .

Thus, s_{ij} becomes a set of links: $\{l_{ij1}, l_{ij2}, \dots\}$, where l_{ijk} is a link with thickness t_{ijk} . Then, nor-

malize thickness of the links as $\sum_k t_{ijk} = 1$, in each s_{ij} .

Step 2. For each node P_i , compute thickness h_{ij} of each subréférent s_{ij} in the following way:

1. Let m_i be the number of subréférents of P_i .
2. Let h_{ij} be $2m_i - 1 - j$.
(Note that $h_{i1} : h_{im} = 2 : 1$.)
3. Normalize thickness h_{ij} as $\sum_j h_{ij} = 1$, in each P_i .

Step 3. Generate référé of each node in *Paradigme*, in the following way:

1. For each node P_i in *Paradigme*, let its référé r_i be an empty set.
2. For each P_i , for each subréférent s_{ij} of P_i , for each link l_{ijk} in s_{ij} :
 - a. Let p_{ijk} be the node referred by l_{ijk} , and let t_{ijk} be thickness of l_{ijk} .
 - b. Add a new link l' to référé of p_{ijk} , where l' is a link to P_i with thickness $t' = h_{ij} \cdot t_{ijk}$.
3. Thus, each r_i becomes a set of links: $\{l'_{i1}, l'_{i2}, \dots\}$, where l'_{ij} is a link with thickness t'_{ij} . Then, normalize thickness of the links as $\sum_j t'_{ij} = 1$, in each r_i .

Appendix B. Function of Paradigme — Spreading Activation Rules

Each node P_i of the semantic network *Paradigme* computes its activity value $v_i(T+1)$ at time $T+1$ as follows:

$$v_i(T+1) = \phi \left(\frac{R_i(T) + R'_i(T)}{2} + e_i(T) \right),$$

where $R_i(T)$ and $R'_i(T)$ are activity (at time T) collected from the nodes referred in the référent and référé respectively; $e_i(T) \in [0, 1]$ is activity given from outside (at time T); the output function ϕ limits the value to $[0, 1]$.

$R_i(T)$ is activity of the most plausible subréférent in P_i , defined as follows:

$$R_i(T) = S_{im}(T),$$

$$m = \operatorname{argmax}_j \{h_{ij} \cdot S_{ij}(T)\},$$

where h_{ij} is thickness of the j -th subréférent of P_i . $S_{ij}(T)$ is the sum of weighted activity of the nodes referred in the j -th subréférent of P_i , defined as follows:

$$S_{ij}(T) = \sum_k t_{ijk} \cdot a_{ijk}(T),$$

where t_{ijk} is thickness of the k -th link of s_{ij} , and $a_{ijk}(T)$ is activity (at time T) of the node referred by the k -th link of s_{ij} .

$R'_i(T)$ is weighted activity of the nodes referred in the référé r_i of P_i :

$$R'_i(T) = \sum_k t'_{ik} \cdot a'_{ik}(T),$$

where t'_{ik} is thickness of the k -th link of r_i , and a'_{ik} is activity (at time T) of the node referred by the k -th link of r_i .

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