Comparative Study of Self-Organizing Semantic Cognitive Maps Derived from Natural Language

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Introduction

Cognitive mapping as a general biological method of information processing acquires increased attention in cognitive science. A cognitive map is understood here as an abstract metric space with symbols allocated in it, such that the relative locations of symbols reflect their semantics. Linguistic cognitive maps that capture synonym-antonym relations (Samsonovich & Ascoli 2007) possess universality in terms of their geometry and semantics across languages (English, French, Spanish), data types and methodologies (linguistic corpora vs. introspective word ranking by human subjects vs. psychometric data). Here we continue this study using self-organization of the map based on an energy function derived from a very general statistical hypothesis that synonyms are normally distributed on the map. In addition, we disregard antonym relations among words. One of the findings is that antonym relations appear to be vital for global self-organization of a semantic cognitive map.

Materials and Methods

In this study we used the WordNet-3.0 database developed at Princeton University: http://wordnet.princeton.edu/ and the ANEW database (Bradley & Lang, 1999) developed by CSEA at the University of Florida. The set of words was limited to those that appear in both databases and are each connected by at least two synonym relations to the cluster.

The general paradigm of a self-organizing cognitive map (Samsonovich & Ascoli 2007) is to look for a minimum energy state of the system of words. In the present study we define the energy function H of the system based on a P-value consistent with the statistical model assuming that synonyms of any given word have a standard Gaussian distribution centered at the given word in the abstract space:

$$H = \sum_{p \in S} d_p^2 + \alpha \sum_{p \notin S} \exp\left(-d_p^2\right).$$

Here p is a pair of words, S is the set of pairs of synonyms, and d_p is the distance between the two words. The only parameter of the model α is calculated using an elegant method, from the sparsity of the dictionary of synonyms.

Results

The findings are as follows. (a) The map forms reproducively in a ten-dimensional space, while in three dimensions results depend on initial conditions, indicating predominance of local minima. (b) Similarly to the previous findings, only the first six principal components in the ground state are significant. (c) The resultant map is semantically consistent at a local scale: the lengths of all synonym links are small compared to the maximal spread of the distribution. (d) In contrast with the previous study that included antonyms, the principal components of the distribution of words taken globally do not possess unambiguous semantics, as found by measuring correlations with the ANEW dimensions (the maximal correlation coefficient with ANEW dimensions is 0.5).

Discussion and Conclusions

Based on the above results, we speculate that (a) there is a threshold dimensionality of the map that is critical for its self-organization; (b) at the same time, a self-organized map exhibits a low-dimensional distribution; (c) a locally-organized map is produced reliably with the selected energy function; (d) however, antonym relations appear to be vital for global self-organization of semantic cognitive maps.

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