Available online at www.sciencedirect.com
SciVerse ScienceDirect
Cognitive Systems Research 19–20 (2012) 30–38
Cognitive Systems RESEARCH
www.elsevier.com/locate/cogsys

A corpus-based computational model of metaphor understanding consisting of two processes

Action editor: Stefan Wemter

A. Terai [a,*], M. Nakagawa [b]

[a] Global Edge Institute, Tokyo Institute of Technology, 2-12-1 O-okayama Meguro-ku, Tokyo 152-8550, Japan
[b] Graduate School of Decision Science and Technology, Tokyo Institute of Technology, 2-12-1 O-okayama Meguro-ku, Tokyo 152-8550, Japan

Received 16 December 2011; accepted 24 February 2012
Available online 24 March 2012

Abstract

The purpose of this study is to construct a computational model of metaphor understanding based on statistical corpora analysis and that includes dynamic interaction among features. The constructed model consists of two processes: a categorization process and a dynamic-interaction process. The categorization process model, which is based on the class inclusion theory, represents how a target is assigned to an ad hoc category of which the vehicle is a prototypical member. The dynamic-interaction process model represents how the target assigned to the ad hoc category is influenced and how emergent features are emphasized by dynamic interactions among features. The dynamic interaction is realized based on a recurrent neural network. The constructed model is able to highlight the emphasized features of a metaphorical expression. Finally, real-world experiments are conducted in order to verify the semantic validity of the constructed model of metaphor understanding with dynamic interactions. The results from the real-world experiments support the model incorporating dynamic interaction.

Keywords: Neural network; Language statistical analysis; Metaphor understanding; Dynamic interaction

1. Introduction

This paper constructs a computational model that realizes the understanding processes for metaphorical expressions, represented in the form of "TARGET like VEHICLE", where a noun ("TARGET") is modified by another noun ("VEHICLE"). Metaphor understanding basically requires a knowledge structure for nouns (a target, a vehicle and so on) (Kusumi, 1995). However, it is not practically feasible to collect sufficient data to cover enough nouns by psychological methods alone, because participants cannot rate the entire range of nouns that are commonly used in metaphorical expressions within limited amounts of time. Thus, a model based only on psychological experimentation cannot be extended to computational systems (e.g. search engines). Accordingly, in this paper, a computational model is constructed based on a knowledge structure for nouns extracted from linguistic corpora without human judgments.

Generally speaking, there are two theories that seek to account for the understanding processes for similes ("TARGET is like VEHICLE") and metaphors ("TARGET is VEHICLE") within psychology. One is the comparison theory, which holds that metaphor understanding is realized by aligning with each other similar elements between the target and the vehicle (Gentner & Wolff, 1997). For example, in comprehending the metaphor "Socrates is like a midwife", the understanding process is

* Corresponding author. Tel./fax: +81 3 5734 3773.
E-mail addresses: asuka@nm.hum.titech.ac.jp (A. Terai), nakagawa@nm.hum.titech.ac.jp (M. Nakagawa).

1389-0417/$ - see front matter
http://dx.doi.org/10.1016/j.cogsys.2012.03.001

realized when similar elements relating to "Socrates helps students to give birth to their ideas" and "a midwife helps mothers to give birth to their children" and are mutually aligned. In other words, this metaphor is comprehensible when one notices that Socrates was someone who "helped" his students to give birth to certain ideas and that a midwife is someone who "helps" pregnant women to give birth to their children. However, it is difficult to estimate the structures of concepts required for the theory using corpus data without human judgments.

The second theory is the categorization theory. Here, metaphor understanding is explained in terms of class-inclusion statements, where a target is regarded as a member of an ad hoc category of which the vehicle is a prototypical member (Glucksberg & Keysar, 1990). For example, in comprehending the metaphor of "Socrates is like a midwife", the target of "Socrates" is considered to belong to a "helpful" category which could be typically represented by a vehicle like "midwife".

Some computational models of metaphor understanding have been constructed using linguistic corpora based on the class inclusion theory (e.g. Kintsch, 2000; Utsumi, 2006; Terai & Nakagawa, 2007b, 2010). Kintsch's and Utsumi's models have employed knowledge structures estimated with Latent Semantic Analysis (LSA) (Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990). Even though noun meanings are represented by vectors in LSA, the vector dimensions themselves do not have meaning. Thus, the meaning of a noun represented by a particular vector must generally be defined in terms of the cosines of the angles between other vectors according to the LSA method. This aspect of LSA makes it difficult to interpret metaphors represented by vectors. And, other models (Terai & Nakagawa, 2007b, 2010) have employed knowledge structures estimated with a statistical language analysis (Kameya & Sato, 2005). In this method, the meaning of a noun is represented by a set of conditional probabilities of the noun given the features. In this case, each dimension of the vector has its own meaning as a feature. This makes it easier to determine the estimated meaning of a metaphor than with the LSA approach.

On the other hand, it is worth noting that some studies have focused on the features, which are not typically thought of in relation to either the target or the vehicle alone, come to mind when the target and vehicle enter into a metaphoric comparison; the features are regarded as emergent features and a phenomenon of the emergent features are referred to as feature emergence (Becker, 1997; Nueckles & Janetzko, 1997; Gineste, Indurkhya, & Scart, 2000). And the previous researches reported that the emergent features play important roles in metaphor understanding. Feature emergence has also been described in terms of an interaction among features (Utsumi, 2000; Terai & Nakagawa, 2007a, 2007b, 2010). One model (Utsumi, 2000) represents feature emergence using the relationships between features, but the model does not represent the dynamic interaction among features. The dynamic interaction among features indicates the mechanism that features influence each other mutually and representation of the metaphor changes dynamically in metaphor comprehension. In contrast, other models (Terai & Nakagawa, 2007a, 2007b, 2010) represent the phenomenon using dynamic interactions among features. Especially, the model (Terai & Nakagawa, 2007b, 2010) consists of two processes; the first is a categorization process and the second is a dynamic-interaction process and the model has been demonstrated to achieve a measure of success. However, Terai & Nakagawa's models (Terai & Nakagawa, 2007b, 2010) were constructed only using frequency data for adjective–noun modifications. Thus, the represented features for nouns in the model were limited to adjectives, and, consequently, the model cannot represent the understanding process for metaphors involving "verbs" (e.g. "a rumor like a virus" with the underlying meaning of "a rumor that spreads like a virus"). Moreover, the meaning of a metaphor is represented by the sigmoid function outputs through dynamic interaction. In order to make differential equations converge, the sigmoid function is used. There is no cognitive reason why the sigmoid function is used. In this research, it is assumed that the influence of the interactions among features decreases over time. Thus, differential equations that converge over time are developed for the dynamic-interaction process.

Similar to Terai& Nakagawa's models (Terai & Nakagawa, 2007b, 2010), the present study also assumes that metaphor understanding is realized through two processes (categorization and dynamic-interaction processes). In order to overcome problems with previous models, the present model is constructed as follows. First, nouns are represented using vectors that are estimated from a statistical language analysis (Kameya & Sato, 2005) for four kinds of modification patterns (frequency data for adjective–noun modifications and three kinds of verb–noun modifications). The meanings of nouns estimated from the statistical language analysis are represented by conditional probabilities for the nouns given the features. This makes it easier to determine estimated meanings than with the LSA approach. In addition, features are expressed using not only adjectives but also for verbs within four modification patterns. Second, the categorization-process model is constructed based on the class inclusion theory (Glucksberg & Keysar, 1990). Here, metaphor understanding is explained in terms of class-inclusion statements, where an ad hoc category of which the vehicle is a prototypical member is constructed to interpret the metaphor and a target is regarded as a member of the ad hoc category. The model assigns the meaning of a target to an ad hoc category for the vehicle using estimated noun vectors. Third, a recurrent neural network model using differential equations to represent the dynamic-interaction process estimates the meaning of the metaphor based on the assigned meaning of the target (the results of the categorization model). In order to incorporate the emphasized features of the metaphor expression, differential equations that