A Geometric Method for Context Sensitive Distributional Semantics

by

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Abstract

This thesis describes a novel methodology, grounded in the distributional semantic paradigm, for building context sensitive models of word meaning, affording an empirical exploration of the relationship between words and concepts. Anchored in theoretical linguistic insight regarding the contextually specified nature of lexical semantics, the work presented here explores a range of techniques for the selection of subspaces of word co-occurrence dimensions based on a statistical analysis of input terms as observed within large-scale textual corpora. The relationships between word-vectors that emerge in the projected subspaces can be analysed in terms of a mapping between their geometric features and their semantic properties. The power of this modelling technique is its ability to generate ad hoc semantic relationships in response to an extemporaneous linguistic or conceptual situation.

The product of this approach is a generalisable computational linguistic methodology, capable of taking input in various forms, including word groupings and sentential context, and dynamically generating output from a broad base model of word co-occurrence data. To demonstrate the versatility of the method, this thesis will present competitive empirical results on a range of established natural language tasks including word similarity and relatedness, metaphor and metonymy detection, and analogy completion. A range of techniques will be applied in order to explore the ways in which different aspects of projected geometries can be mapped to different semantic relationships, allowing for the discovery of a range of lexical and conceptual properties for any given input and providing a basis for an empirical exploration of distinctions between the semantic phenomena under analysis. The case made here is that the flexibility of these models and their ability to extend output to evaluations of unattested linguistic relationships constitutes the groundwork for a method for the extrapolation of dynamic conceptual relationships from large-scale textual corpora.

This method is presented as a complement and a counterpoint to established distributional methods for generating lexically productive word-vectors. Where contemporary vector space models of distributional semantics have almost universally involved either the factorisation of co-occurrence matrices or the incremental learning of abstract representations using neural networks, the approach described in this thesis preserves the connection between the individual dimensions of word-vectors and statistics pertaining to observations in a textual corpus. The hypothesis tested here is that the maintenance

of actual, interpretable information about underlying linguistic data allows for the contextual selection of non-normalised subspaces with more nuanced geometric features. In addition to presenting competitive results for various computational linguistic targets, the thesis will suggest that the transparency of its representations indicates scope for the application of this model to various real-world problems where an interpretable relationship betweendata and output is highly desirable. This, finally, demonstrates a way towards the productive application of the theory and philosophy of language to computational linguistic practice.

Glossary

base space A high dimensional, sparse vector space of word-vectors, delineated in terms of dimensions of co-occurrence statistics.

context The situation – environmental, cognitive, perceptual, linguistic, and otherwise – in which an agent finds itself and applies language to meaning.

contextual input A set of words characteristic of a conceptual category or semantic relationship used to generate a subspace for the modelling of semantic phenomena.

dimension selection The process of contextually choosing a subset of dimensions in order to project a subspace from a base space.

co-occurrence The observation of one word in proximity to another in a corpus.

co-occurrence statistic A measure of the tendency for one word to be observed in proximity to another across a corpus.

co-occurrence window The boundary defining the proximity within which two words are considered to be co-occurring, typically a distance in terms of words within a sentence.

methodology The process of building base spaces from observations of co-occurrences within a corpus and contextually projecting subspaces through dimension selection.

model An application of methodology to a particular linguistic task or experiment, sometimes including task specific statistical analysis techniques.

subspace A context specific lower-dimensional projection from a base space, effectively mapping semantic relationships to a context by way of the geometric relationships between word-vectors.

word-vector A high-dimensional geometrically situated semantic representation of a word, constructed as an array of co-occurrence statistics.
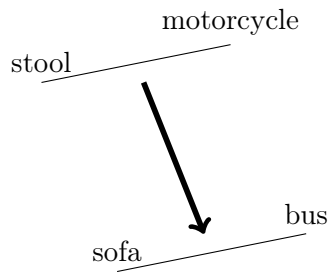
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(a) This makes sense.

(b) Does this make sense?

Figure 2.1: The analogical components of overlapping conceptual frames do not necessarily map neatly into a singular space.

(a) dimension: *life* (b) dimension: *hands* (c) dimension: *known*
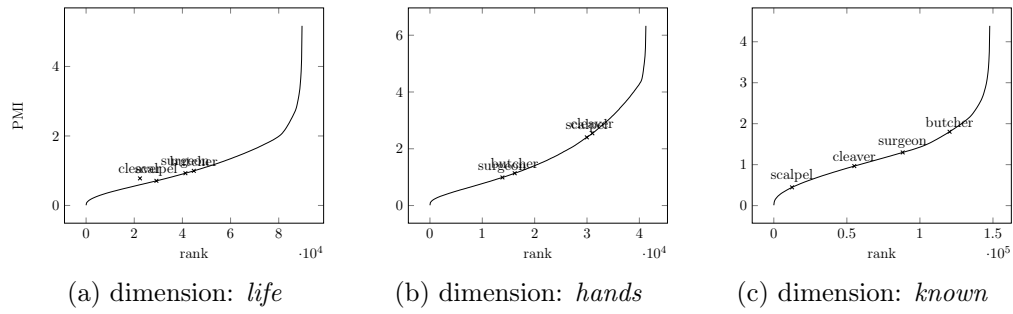
Figure 2.2: Histograms of the top three co-occurrence dimensions satisfying the expected arithmetic of analogy.
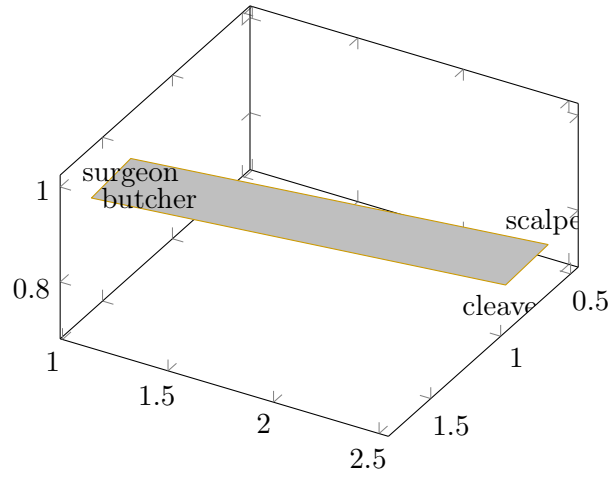
Figure 2.3: An Analogy in Space. When the analogue values of the three dimensions described in Figure 2.2 are plotted, the analogy itself emerges as a parallelogram situated obliquely in the centre of the positive region of the space.
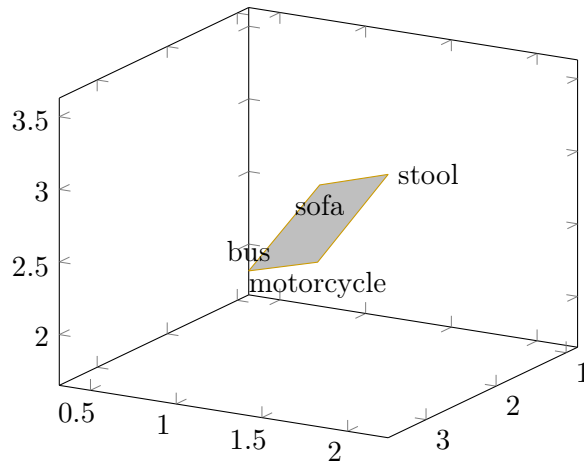
Figure 2.4: An Analogy in Space. When the analogue values of the three dimensions described in Figure 2.2 are plotted, the analogy itself emerges as a parallelogram situated obliquely in the centre of the positive region of the space.

dimensions		5	10	20	50	100	200
2x2	JOINT	0.911	0.972	0.989	0.986	0.970	0.916
	INDY	0.000	0.000	0.001	0.090	0.356	0.677
	ZIPPED	0.921	0.975	0.991	0.987	0.970	0.919
5x5	JOINT	0.941	0.987	0.996	0.997	0.957	
	INDY	0.000	0.000	0.012	0.098	0.202	0.610
	ZIPPED	0.934	0.987	0.999	0.998	0.997	0.968

Table 2-A: Accuracy rates for solving analogies when choosing subsets of optimal dimensions from 400 dimensional subspaces picked taking the first three elements of each analogy as input.

dimensions		5	10	20	50	100	200
2x2	JOINT	0.654	0.814	0.896	0.930	0.881	0.466
	INDY	0.000	0.000	0.000	0.072	0.356	0.636
	ZIPPED	0.616	0.806	0.892	0.929	0.887	0.489
5x5	JOINT	0.657	0.828	0.901	0.921	0.835	0.402
	INDY	0.000	0.000	0.003	0.074	0.225	0.569
	ZIPPED	0.589	0.790	0.888	0.915	0.876	0.418

Table 2-B: Accuracy rates for solving randomly completed analogies when choosing subsets of optimal dimensions from 400 dimensional subspaces picked taking the first three elements of each analogy as input.

Chapter 2

The Geometry of Conceptualisation: Analogies
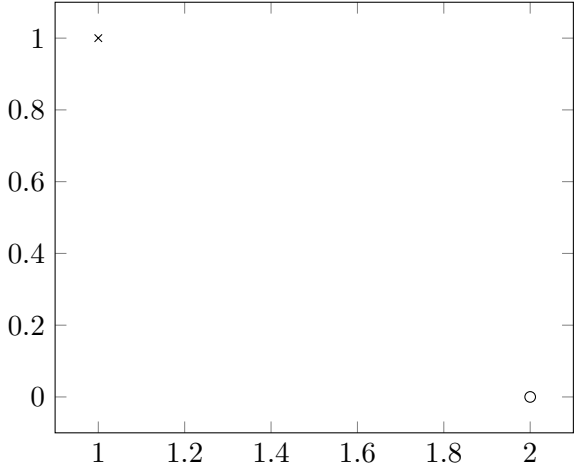
by a high percentage of proper names, in particular place names and also currencies, demonyms, and the like. This belies a particular view of language and indeed cognition which is at odds with the premise motivating the model described in this thesis, as outlined at the beginning of Chapter 3. Proper names are, as **?** has pointed out, particular kinds of words with peculiar denotational properties in that they refer to specific and unique entities or correspondingly specific classes of entities. This is not to say that they do not admit ambiguity – *Paris* is the name of, among other things, a classical character, and *Berlin* the name of a 1980s new wave band – but there tends to be a certain clarity of intent when these types of words are used. These types of analogies are exemplary of cases where language coalesces into a relatively stable conceptual representation, and, notwithstanding cases of polysemy, it's arguably not particularly surprising that these relationships emerge as commensurable directions in a likewise stable representational space.

Furthermore, it is telling that the designers of the dataset have chosen to refer to the variety of analogy typified by *slow:slowly::fast:quickly* as *syntactic*. With reference to **?** and more lately in the distributional semantic paradigm **?**, I would rather call this type of analogy *syntagmatic*, in that

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