

[[Something Pithy]]:
A Geometric Method for Context Sensitive
Distributional Semantics

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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 between data and output is highly desirable. This, finally, demonstrates a way towards the productive application of the theory and philosophy of language to compu-

tational 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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Chapter 3

Metaphor and Coercion

In this chapter, I will extend the empirical work on exploring the application of my context sensitive distributional semantic models to two semantic phenomena which involve the application of words in situations where their meanings are in some sense conceptually altered: *metaphor* and *semantic type coercion*. The precise definitions of these terms, which are not without nuance, was explored in Chapter ?? and will be reintroduced in subsequent sections. As an overview, the distinguishing characteristic of these phenomena is that they involve cases where what might be thought of as the stable, encyclopedic understanding of some word sense – a *dictionary definition* of a word, so to speak – is in some way appropriated or subverted in order to, among other things, transfer information via the attributional conduits connecting figurative source to literal target.

My hypothesis is that, because figurative language always involves the contextual specification of word meaning, context sensitive geometries of lexical representations should provide an appropriate framework for identifying when this type of semantic phenomenon is in effect. ? demonstrates empirically that metaphor interpretation is, when a metaphor is presented to a subject out of context, an ambiguous exercise, and, to the extent that interpretations of de-contextualised metaphors can be predicted, the predicting factors are themselves culturally relative. Along similar lines, ? propose that metaphor production involves the contextual alignment of overlapping semantic frames, and that this alignment likewise imports structure associated with one frame into the domain of another, evident in, for instance, the additional transposition of syntactic constraints from source to target. From a cognitive perspective, this coordinates a contextual theory of metaphor with the work on conceptual frames from ?? discussed at the end of the previous chapter in the context of judgements of semantic similarity. From a modelling perspective, this suggests that a methodology for projecting semantic spaces where context specific perspectives can reveal *ad hoc* perspectives on semantic relationships should be a productive approach to identifying figurative language.

The idea that metaphor and metonymy are both instances of “a connection between two things where one term is substituted for another,” (?, p. 260) will quickly call to mind the premise of distributional semantics: if the motivation for building vector space models of word co-occurrence statistics is that related words have similar co-occurrence tenden-

cies, then figurative language might be construed as a special case in which unrelated or at least conceptually divergent words are likewise found in similar sentential situations. The question, then, is whether statistical characteristics of the particular co-occurrences profiles selected by words with different meanings are predictive of figurativeness. A naive hypothesis might be that word combinations that are figurative should simply be further apart in a semantic space than word combination that are literal. If related words have similar co-occurrence profiles, then maybe unrelated words, for instance words with different conceptual entailments, should have less similar co-occurrence profiles. This conjecture, however, is belied first of all by the fact that, in the type of corpus containing a broad range of examples of language use necessary for building distributional semantic models, figurative language will already be built into the data (and at the end of this chapter I will argue, in line with, for instance, ?, that figurative language is going to be built into any sample of language no matter how small or basic). A second problem is that, specifically to overcome the problems with modelling semantic relationships merely in terms of collocations, distributional semantics compares the co-occurrence profiles of words rather than their direct relationships, and it seems likely that word combinations prone to metaphoric interpretation might very well have at least overlapping profiles.

So the objective of the experiments reported in this chapter will be to explore the ways in which and the degrees to which a more fleshed out statistical description of contextually selected distributional semantic subspaces can reveal figurative language. As with the experiments on relatedness and similarity reported in the previous chapter, in addition to the relationship between target word-vectors in the subspaces they select, the statistical properties of the selected dimensions themselves will also be examined. And, again as with previous results, the instrument of analysis will be the geometric features of the subspaces in question, with, again, particular attention paid to the way in which the sets of features can collectively indicate figurative language. The two primary datasets explored represent binary decisions about metaphoricity and coercion respectively, and so my models will be applied to classification tasks here. In the case of metaphor, I test whether a model learned based on classification data is generalisable to graduated human ratings of metaphoricity. With the coercion data, I will examine whether the addition of information about sentential context enhances the classification of word pairs. I will conclude the chapter with a reflection on some of the theoretical implications of the strongly positive results described here.

The study of why humans use figurative language has a considerable scholastic pedigree.

It has served as something of a bafflement to logical empiricists from

3.1 An Experiment on Metaphor

As pointed out by ?, statistical approaches to metaphor identification and interpretation have generally been formulated in the context of the *conceptual metaphor* theory of ?. This model is founded on the principle that “we systematically use inference patterns from one conceptual domain to reason about another conceptual domain,” (ibid, p. 246).

Metaphors are then the mechanism for performing the mapping between these domains, and as such cut right to the core of cognitive processes. Statistical models of metaphor have accordingly treated metaphors as transformations of lexical representations, and vector space models of distributional semantics have naturally leant themselves to this type of approach. The construction of representations with the potential to interact with one another in semantically productive ways has in turn lent itself to the development of models that consider the compositional nature of metaphor, effectively treating the metaphor itself as a transformation of the underlying representations. So ? constructs candidate metaphor-vectors by calculating the centroid of a number of vectors derived from an analysis of a noun-vector and a predicate-vector learned through latent semantic analysis, and then uses the spatial relationships between these composed vectors to analyse the metaphoricity of certain phrases. ? similarly consider composition in their approach to metaphor classification, in this case by combining word-vector type representations with a model trained to identify metaphor based on dependency trees of sentences labelled for metaphoricity.

In the tradition of work on compositional distributional semantics explored by the likes of ?, ?, and ?, among others, semantic types such as adjectives and verbs are modelled as tensors which perform transformations on nouns, which are modelled as vectors. In the normal run of things, compositional models therefore represent, for instance, noun phrases modified by adjectives as the product $A\vec{n}$, where A is a matrix representing an adjective learned from observations of attested instances of the adjective with other noun word-vectors. So the phrase *black dog* becomes a word-vector in the same space as the representation of just *dog*, and can be compared quantitatively and geometrically with other phrases such as *white dog* or *big cat* and so forth. In the case of metaphor, these transformations are expected to map the word-vector representing metaphoric phrases into a region corresponding to the semantic domain of the original noun-vector modified by a metaphoric interpretation of the word associated with the tensor of a modifier or a predicate. So, for instance, in a model that effectively captures metaphoricity, the composition of the vector space representations corresponding to *brilliant light* would map to a region of space where comparisons between phrases like *dark illumination* and *red glow* are productive, while *brilliant child* might be expected to map into the proximity of *stupid boy* and *boring girl*.¹

The data that I will use in this section to test my methodology was originally presented by ?, along with an accompanying experiment on a novel model. It consists of 8,592 adjective-noun pairs, spanning 23 adjectives chosen for their membership in six different broad semantic categories that are prone to both literal and metaphoric use: so, for instance, *bitter*, *sour*, and *sweet* are considered constituents of the category TASTE. There are 3,473 different noun types used, with only 141 types, represented by 640 tokens, occurring in both literal and metaphoric phrases. Each pair has been rated as either literal or metaphoric by a pair of human annotators, with inter-annotator agreement measuring at Cohen’s $\kappa = 0.80$. This dataset was conceived as something of an expansion of the similar but smaller corpus of adjective-noun phrases annotated with binary metaphoricity classifications presented by ? (and those authors tested their own data with an assortment

¹It should be noted that such a methodology at this point begins to assume dim shades of Gärdenfors’s (2000) conceptual spaces, with different compositions inherently defining different regions of the space.

of models, achieving highest f-scores by applying a random forest classifier to the features of an existing library of distributional semantic word-vectors).

In their own experimental treatment of the data, ? constructed a pair of compositional models in the mode of ?, learning adjective matrixes A to map from noun-vectors to noun-adjective phrase-vectors extracted from observations of co-occurrences of both nouns and phrases in a corpus. By creating separate tensor representations for literal and metaphoric instances of a given adjective, the authors can then compare the relationships between the vectors resulting from a noun-vector composed with literal and metaphoric senses of an adjective-vector to try to determine whether a given phrase would generally be classified as a metaphor or a literal expression by comparing the respective compared vectors to the phrase-vector as observed in the corpus. In a further attempt to generalise the method, and, notably, to apply the conceptual metaphor theory of ? to their computational model, the authors learn matrices performing linear transformations from literal to metaphoric adjective-noun compositions and then compare the similarity between observed phrase-vectors and literal composed vectors versus transformed literal composed vectors to determine whether a given phrase is metaphoric or not.

The data described by ? will serve as the basis for testing my own context sensitive distributional semantic methodology’s ability to classify phrases as literal or metaphoric, and the results of this experiment will be described in the following section. My hypothesis is that metaphor, and indeed all figurative language, is fundamentally entangled with the context mutually indicated by the representations of the words participating in the composition being analysed. In fact, I think that part of what is captured by the model described by ?, and indeed a number of other researchers investigating statistical methods for metaphor classification, is precisely that there is a context inherent in the linear algebraic dynamics of composable lexical representations, and this is something which many researchers explicitly recognise. But I also think that the explicit projection of context specific semantic subspaces, the mainstay of my methodology, should provide an ideal testing ground to discover the way in which statistical geometry can directly broadcast the presence or absence and even potentially the degree of metaphor inherent in a given phrase. The following sections will test this hypothesis using a similar methodology to that applied to semantic relatedness and similarity in the previous chapter.

3.1.1 Methodology and Results

My own methodology is clearly less committed to maintaining distinct representations for different semantic types than the compositional models described above, instead modelling all words as untagged word-vectors based on their co-occurrences as observed across a large scale corpus. This feature of my research is in part theoretically motivated: in line with ?, and *contra* the grammatic nativism or exceptionalism that has been a mainstay in theoretical linguistics (?), I would like to investigate the possibility that “grammar is fully and appropriately describable using only symbolic units, each having both semantic and phonological import,” (ibid, p. 290). In other words, the syntactic component of a natural language might be described in terms of the entanglements of the meaning-making structures – the lexical semantic representations – that arise in the course of language

<i>window</i> <i>dimensions</i>	2x2				5x5			
	20	50	200	400	20	50	200	400
JOINT	0.839	0.860	0.878	0.881	0.840	0.862	0.880	0.886
INDY	0.821	0.839	0.855	0.860	0.817	0.840	0.858	0.867
ZIPPED	0.839	0.864	0.876	0.878	0.833	0.854	0.873	0.880
ADJECTIVE	0.771	0.860	0.828	0.845	0.781	0.804	0.828	0.837
NOUN	0.819	0.861	0.843	0.847	0.806	0.821	0.838	0.843
SVD	0.685	0.703	0.703	0.697	0.677	0.694	0.687	0.684
SG	0.679	0.676	0.679	0.673	0.664	0.665	0.672	0.656
CBOW	0.669	0.681	0.677	0.672	0.669	0.673	0.677	0.671

Table 3-A: F-scores for metaphor identification based on a ten-fold cross-validated logistic regression taking geometric features of various subspace types as input.

use, or maybe even as emergent properties of these entanglements.

With this in mind, I will approach the problem of metaphor classification with a similarly statistical and geometric methodology as was applied to relatedness and similarity in the previous chapter, outside of any *prima facie* model of syntax or compositionality. For every pair of words in the data produced by ?, I generate subspaces of 20, 50, 200, and 400 dimensions using the JOINT, INDY, and ZIPPED techniques, projected from 2x2 and 5x5 word co-occurrence window base spaces. This data specifies a distance role for each word, one being a metaphoric source (the adjective) and the other being a target (the noun): so, for instance, a *bitter loss* is a loss, but presumably not one with an actual loss, and so the noun *loss* co-opts something of the quality of bitterness into its own conceptual domain. As such, it might be useful to generate subspaces based simply on an analysis of the word-vectors corresponding to the adjective and the noun respectively. I do this by simply selecting the top d dimensions, in line with the dimensionality parameter for each model, for the term in question, and these spaces are labelled ADJECTIVE and NOUN in the results that follow.

In each subspace, I extrapolate the same 34 geometric features described in Table ?? and applied in the previous chapter in the semantic relatedness and similarity experiments. Again because of the semantic asymmetry of the relationship between the input terms, an additional seven features are also available in these spaces: the adjective-vector norm divided by the noun-vector norm (A/B), likewise the lengths of the vectors between the adjective and the generic points divided by the lengths for the noun-generic-point vectors ($\overline{AC}/\overline{BC}$, $\overline{AM}/\overline{BM}$, and $\overline{AX}/\overline{BX}$), and the corresponding fractions of the normalised versions of these points ($\overline{A'C'}/\overline{B'C'}$, $\overline{A'M'}/\overline{B'M'}$, and $\overline{A'X'}/\overline{B'X'}$). These additional measures might offer a sense of whether there are statistical tendencies that are specific to the semantic role being played by a word moving from literal to metaphorical relationships, and we might expect this to be particularly evident in the spaces selected by either the noun or the adjective on their own.

In order to test the capacity of the geometric features of my subspaces to identify metaphor, I perform a logistic regression taking these features as independent variables and learning to predict the classifications assigned to the word pairs in the dataset.

Balanced f-scores based on the precision and recall of my various dimensional selection techniques as well as static SVD factorisations of my base spaces and the `word2vec` models are reported in Table 3-A. The first thing to note is the strong performance across the board of the context sensitive methodology: the least predictive versions of my models still substantially outperform the strongest versions of the static models

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The context sensitive results taking both words as input display a systematic advance as dimensionality and co-occurrence window size progress, suggesting that more information about co-occurrences, arising from larger co-occurrence windows and deeper analysis of salient co-occurrence terms corresponding to higher dimensionality, leads to more information about the likelihood of a metaphorical semantic relationship. The JOINT technique gives the strongest results, suggesting that subspaces delineated in terms of co-occurrence dimensions mutually salient to both input terms offer the best platform for analysing metaphoricity. This makes sense: in the case of metaphor versus literalness, it is the co-occurrences that both words have in common that position their respective word-vectors in an indicative relationship relative to one another and the subspace overall. So for instance the co-occurrences salient to both *sweet* and *fruit* will have a particular conceptual profile that will not be evident in the dimensions jointly selected by *sweet* and *revenge*; this effect will be less evident for dimensions independently salient to each word. ZIPPED subspaces, where there will be at least some information about both words along every dimension, accordingly score almost as well as JOINT subspaces, with the INDY subspaces falling further behind.

Interestingly, the ADJECTIVE and NOUN spaces classify metaphor most accurately in 50 dimensional subspaces projected from the 2x2 word window base space. To the extent that part-of-speech can be a component of the analysis of these models, we can expect the smaller co-occurrence window to produce statistics that are more indicative of a particular grammatical class. The degradation of classification at higher dimensionalities for the smaller co-occurrence window setting is a little surprising, and it's worth noting that the INDY subspaces, which are basically blends of the ADJECTIVE and NOUN subspaces, don't exhibit the same tendency. In this case, it would seem the whole really is greater than the sum of the parts, with the dimensional selection of one word providing at least a degree of useful information about the other word not available in spaces salient to a single term. A similar pattern emerges for the static spaces: the SVD, SG, and CBOW models all produce the most accurate classifications in 2x2 word window, 50 dimensional subspaces. One way to explain this is that more ambiguous information about word use begins to leak in at higher dimensionalities, serving to obscure the more standard indications available in either the most salient dimensions or the dimensions containing the most information about variance across the corpus.

So it is possible that a model is detecting something about a particular adjective's propensity to be involved in a metaphor, and then learning a combination of features that effectively serve to label each adjective in a way that is mappable to a fairly reliable classification.

As a final point of comparison with other approaches to metaphor classification, I

<i>window dimensions</i>	2x2				5x5			
	20	50	200	400	20	50	200	400
JOINT	0.815	0.834	0.853	0.856	0.813	0.833	0.855	0.862
INDY	0.781	0.794	0.827	0.834	0.771	0.801	0.824	0.841
ZIPPED	0.809	0.835	0.845	0.852	0.793	0.823	0.841	0.849
ADJECTIVE	0.617	0.834	0.751	0.787	0.686	0.689	0.767	0.696
NOUN	0.805	0.834	0.826	0.829	0.794	0.809	0.821	0.826
SVD	0.679	0.691	0.695	0.690	0.665	0.674	0.678	0.676
SG	0.668	0.664	0.659	0.657	0.659	0.656	0.644	0.638
CBOW	0.657	0.665	0.665	0.661	0.656	0.660	0.666	0.660

Table 3-B: F-scores for metaphor identification with each of the conceptual categories identified by ? treated as a separate fold for cross-validation.

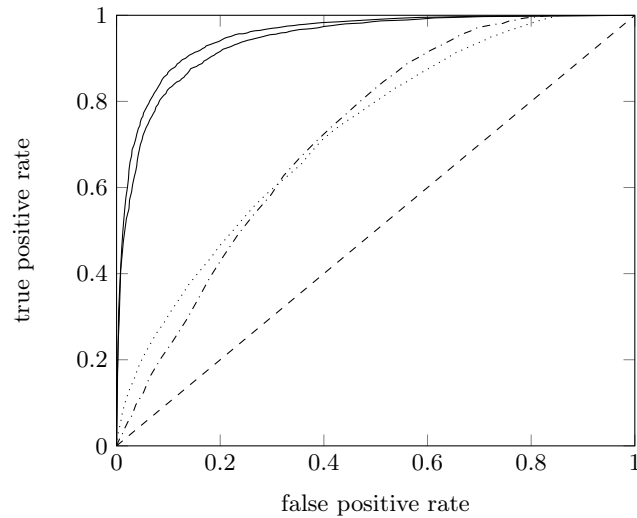


Figure 3.1: Receiver operator characteristic plots for a selection of models, with the area under the curve for each model type indicated in the legend.

will return briefly to the unannotated character of my lexical representations, mentioned above in the context of

In addition to allowing for a commitment to

3.1.2 The Geometry of Metaphor

3.1.3 Generalising the Model

One of the interesting things about feature-based classification is that there is always an inherent commitment to degree of class membership, even when the training data used to build a model is simply binary. This is true of any model which uses, for instance, a logistic regression technique for determining class, as there is a cut-off point along the

JOINT		INDY		ZIPPED		ADJECTIVE		NOUN	
$\mu(A, B)$	0.787	C	0.767	$\mu(A, B)$	0.788	$\mu(A, B)/M$	0.745	$\mu(A, B)$	0.756
C	0.771	C/M	0.749	C	0.771	$\overline{AC} : \overline{BC}$	0.736	C	0.747
$\mu(A, B)/M$	0.764	$\angle AMB$	0.747	$\mu(A, B)/M$	0.769	$\overline{AC}/\overline{BC}$	0.734	$\mu(A, B)/X$	0.728
$\angle COX$	0.762	C/X	0.746	X	0.767	$\mu(A, B)/X$	0.732	$\mu(A, B)/M$	0.721
X	0.762	$\mu(A, B)$	0.734	$\mu(A, B)/X$	0.759	$\angle ACB$	0.730	C/X	0.721

Table 3-C: Independent f-scores from the metaphor classification data for top five features of each subspace type for 5x5 word co-occurrence window, 400 dimension subspaces.

spectrum of model output and a corresponding proximity to that point for any given sample, and it is especially obvious when the features of the model are actually geometrical measures. In this section, I will apply the models learned from the $?$ data to another dataset designed to assess metaphor as a matter of degree rather than simply as a binary situation

3.2 An Experiment on Coercion

Returning to the theoretical issues regarding grammaticality raised earlier in this chapter, this analysis of coercion points to something more like a graduated typology, sliding from specific instances of, for instance, processes, things, or attributes to more general conceptual categories and finally to entire classes of words.

3.2.1 Methodology and Results

3.2.2 The Geometry of Coercion

3.2.3 Adding Sentential Context

3.3 Interpretation and Composition in Context

In fact, it is tempting to go so far as to say that figurative language is identified precisely as those instances of language where recourse to a conceptual context is necessary to interpret a lexical composition, and furthermore that the degree of figurativeness correlates with the extent of context construction involved in an interpretation. This proposition is in line with $?$'s (?) empirical work treating metaphor interpretation as a mechanism for classification

This, then, raises a valid question: is the role of figurative language exclusively, or even for that matter primarily, to port attributes from one conceptual domain to another? Or is what metaphor does, as $?$ has famously suggested, really about something more fundamentally phenomenological than just the efficient transmission of propositions? So,

where, for instance, ? sees polysemy as an intermediate stage bridging the progress from literal to metaphoric usage, my methodology leaves itself open to the possibility that all usage is, in fact, first and foremost pragmatic, and only secondarily lexicalised. By this interpretation, words have semantic affordances in terms of their potential to convey cognitive content intersubjectively, and they are picked up and used in much the same way that a cognitive agent might adapt an object designed or just perceived as being for one purpose as an implement in another activity—using a shoe as a hammer, for example, or a chair to fend off a lion. The cognitive foregrounding of this nascent theory can be found in the ecological psychology of ? and ?, and the linguistic correlary seems to be in line with what psycholinguists inspired by biosemiotics such as ? are saying about the way that language is primarily about affording cognitive value to interlocutors, including but hardly limited to truth values.

This theoretical speculation is a potential extrapolation of my methodology rather than a precondition for it, and is offered primarily as an example of how this statistical approach might become a component of productive line of philosophical enquiry. The point, though, is that with a geometric methodology, relationships between lexical semantic representations can be recast as Gibsonian affordances: there is a mechanism for the direct perception of opportunities for meaning making in the actual layout of the statistical environment

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