Computing Lexical Contrast

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Knowing the degree of semantic contrast between words has widespread application in natural language processing, including machine translation, information retrieval, and dialogue systems. Manually created lexicons focus on opposites, such as hot *and* cold*. Opposites are of many kinds such as antipodals, complementaries, and gradable. Existing lexicons often do not classify opposites into the different kinds, however. They also do not explicitly list word pairs that are not opposites but yet have some degree of contrast in meaning, such as* warm *and* cold *or* tropical *and* freezing*. We propose an automatic method to identify contrasting word pairs that is based on the hypothesis that if a pair of words, A and B, are contrasting, then there is a pair of opposites, C and D, such that A and C are strongly related and B and D are strongly related. (For example, there exists the pair of opposites* hot *and* cold *such that* tropical *is related to* hot*, and* freezing *is related to* cold*.) We will call this the contrast hypothesis.*

We begin with a large crowdsourcing experiment to determine the amount of human agreement on the concept of oppositeness and its different kinds. In the process, we flesh out key features of different kinds of opposites. We then present an automatic and empirical measure of lexical contrast that relies on the contrast hypothesis, corpus statistics, and the structure of a Roget-like thesaurus. We show how, using four different data sets, we evaluated our approach on two different tasks, solving "most contrasting word" questions and distinguishing synonyms from opposites. The results are analyzed across four parts of speech and across five different kinds of opposites. We show that the proposed measure of lexical contrast obtains high precision and large coverage, outperforming existing methods.

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1. Introduction

Native speakers of a language intuitively recognize different *degrees of lexical contrast*—for example, most people will agree that *hot* and *cold* have a higher degree of contrast than *cold* and *lukewarm*, and *cold* and *lukewarm* have a higher degree of contrast than *penguin* and *clown*. Automatically determining the degree of contrast between words has many uses, including:

- Detecting and generating paraphrases (Marton, El Kholy, and Habash 2011) (*The dementors* ***caught*** *Sirius Black / Black could* ***not escape*** *the dementors*).
- Detecting certain types of contradictions (de Marneffe, Rafferty, and Manning 2008; Voorhees 2008) (*Kyoto has a predominantly* ***wet*** *climate / It is mostly* ***dry*** *in Kyoto*). This is in turn useful in effectively reranking target language hypotheses in machine translation, and for reranking query responses in information retrieval.
- Understanding discourse structure and improving dialogue systems. Opposites often indicate the discourse relation of contrast (Marcu and Echihabi 2002).
- Detecting humor (Mihalcea and Strapparava 2005). Satire and jokes tend to have contradictions and oxymorons.
- Distinguishing near-synonyms from word pairs that are semantically contrasting in automatically created distributional thesauri. Measures of distributional similarity typically fail to do so.

Detecting lexical contrast is not sufficient by itself to solve most of these problems, but it is a crucial component.

Lexicons of pairs of words that native speakers consider opposites have been created for certain languages, but their coverage is limited. Opposites are of many kinds, such as antipodals, complementaries, and gradable (summarized in Section 3). Existing lexicons often do not classify opposites into the different kinds, however. Further, the terminology is inconsistent across different sources. For example, Cruse (1986) defines *antonyms* as gradable adjectives that are opposite in meaning, whereas the WordNet antonymy link connects some verb pairs, noun pairs, and adverb pairs too. In this article, we will follow Cruse's terminology, and we will refer to word pairs connected by WordNet's antonymy link as **opposites**, unless referring specifically to gradable adjectival pairs.

Manually created lexicons also do not explicitly list word pairs that are not opposites but yet have some degree of contrast in meaning, such as *warm* and *cold* or *tropical* and *cold*. Further, contrasting word pairs far outnumber those that are commonly considered opposites. In our own experiments described later in this article, we find that more than 90% of the contrasting pairs in GRE "most contrasting word" questions are not listed as antonyms in WordNet. We should not infer from this that WordNet or any other lexicographic resource is a poor source for detecting opposites, but rather that identifying the large number of contrasting word pairs requires further computation, possibly relying on other semantic relations stored in the lexicographic resource.

Even though a number of computational approaches have been proposed for semantic closeness (Curran 2004; Budanitsky and Hirst 2006), and some for hypernymy–

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hyponymy (Hearst 1992), measures of lexical contrast have been less successful. To some extent, this is because lexical contrast is not as well understood as other classical lexical–semantic relations.

Over the years, many definitions of semantic contrast and opposites have been proposed by linguists (Lehrer and Lehrer 1982; Cruse 1986), cognitive scientists (Kagan 1984), psycholinguists (Deese 1965), and lexicographers (Egan 1984), which differ from each other in various respects. Cruse (1986, page 197) observes that even though people have a robust intuition of opposites, "the overall class is not a well-defined one." He points out that a defining feature of opposites is that they tend to have many common properties, but differ saliently along one dimension of meaning. We will refer to this semantic dimension as the **dimension of opposition**. For example, *giant* and *dwarf* are both living beings; they both eat, they both walk, they are both capable of thinking, and so on. They are most saliently different, however, along the dimension of height. Cruse also points out that sometimes it is difficult to identify or articulate the dimension of opposition (for example, *city–farm*).

Another way to define opposites is that they are word pairs with a "binary incompatible relation" (Kempson 1977, page 84). That is to say that one member entails the absence of the other, and given one member, the identity of the other member is obvious. Thus, *night* and *day* are good examples of opposites because *night* is best paraphrased by *not day*, rather than the negation of any other term. On the other hand, *blue* and *yellow* make poor opposites because even though they are incompatible, they do not have an obvious binary relation such that *blue* is understood to be a negation of *yellow*. It should be noted that there is a relation between binary incompatibility and difference along just one dimension of meaning.

For this article, we define **opposites** to be term pairs that clearly satisfy either the property of binary incompatibility or the property of salient difference across a dimension of meaning. Word pairs may satisfy the two properties to different degrees, however. We will refer to all word pairs that satisfy either of the two properties to some degree as **contrasting**. For example, *daylight* and *darkness* are very different along the dimension of light, and they satisfy the binary incompatibity property to some degree, but not as strongly as *day* and *night*. Thus we will consider both *daylight* and *darkness* as well as *day* and *night* as semantically contrasting pairs (the former pair less so than the latter), but only *day* and *night* as opposites. Even though there are subtle differences in the meanings of the terms *contrasting, opposite,* and *antonym*, they have often been used interchangeably in the literature, dictionaries, and common parlance. Thus, we list here what we use these terms to mean in this article:

- **Opposites** are word pairs that have a strong binary incompatibility relation with each other and/or are saliently different across a dimension of meaning.
- **Contrasting word pairs** are word pairs that have some non-zero degree of binary incompatibility and/or have some non-zero difference across a dimension of meaning. Thus, all opposites are contrasting, but not all contrasting pairs are opposites.
- **Antonyms** are opposites that are also gradable adjectives.[1]

1 We follow Cruse's (1986) definition for antonyms. The WordNet antonymy link, however, also connects some verb pairs, noun pairs, and adverb pairs.

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In this article, we present an automatic method to identify contrasting word pairs that is based on the following hypothesis:

> **Contrast Hypothesis**: If a pair of words, *A* and *B*, are contrasting, then there is a pair of opposites, *C* and *D*, such that *A* and *C* are strongly related and *B* and *D* are strongly related.

For example, there exists the pair of opposites *night* and *day* such that *darkness* is related to *night*, and *daylight* is related to *day*. We then determine the degree of contrast between two words using this hypothesis:

> **Degree of Contrast Hypothesis**: If a pair of words, *A* and *B*, are contrasting, then their degree of contrast is proportional to their tendency to co-occur in a large corpus.

For example, consider the contrasting word pairs *top–low* and *top–down*; because *top* and *down* occur together much more often than *top* and *low*, our method concludes that the pair *top–down* has a higher degree of lexical contrast than the pair *top–low*. The degree of contrast hypothesis is inspired by the idea that opposites tend to co-occur more often than chance (Charles and Miller 1989; Fellbaum 1995). Murphy and Andrew (1993) claim that this is because together opposites convey contrast well, which is rhetorically useful. Thus we hypothesize that the higher the degree of contrast between two words, the higher the tendency of people to use them together.

Because opposites are a key component of our method, we begin by first understanding different kinds of opposites (Section 3). Then we describe a crowdsourced project on the annotation of opposites into different kinds (Section 4). In Section 5.1, we examine whether opposites and other highly contrasting word pairs occur together in text more often than randomly chosen word pairs. This experiment is crucial to the degree of contrast hypothesis because if our assumption is true, then we should find that highly contrasting pairs are used together much more often than randomly chosen word pairs. Section 5.2 examines this question. Section 6 presents our method to automatically compute the degree of contrast between word pairs by relying on the contrast hypothesis, the degree of contrast hypothesis, seed opposites, and the structure of a *Roget*-like thesaurus. (This method was first described in Mohammad, Dorr, and Hirst [2008].) Finally we present experiments that evaluate various aspects of the automatic method (Section 7). Following is a summary of the key research questions addressed by this article:

(1) On the kinds of opposites:

> **Research questions:** How good are humans at identifying different kinds of opposites? Can certain term pairs belong to more than one kind of opposite?
>
> **Experiment:** In Sections 3 and 4, we describe how we designed a questionnaire to acquire annotations about opposites. Because the annotations are done by crowdsourcing, and there is no control over the educational background of the annotators, we devote extra effort to make sure that the questions are phrased in a simple, yet clear, manner. We deploy a quality control method that uses a word-choice question to automatically identify and discard dubious and outlier annotations.
>
> **Findings:** We find that humans agree markedly in identifying opposites; there is significant variation in the agreement for different kinds of

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opposites, however. We find that a large number of opposing word pairs have properties pertaining to more than one kind of opposite.

(2) On the manifestation of opposites and other highly contrasting pairs in text:

Research questions: How often do highly contrasting word pairs co-occur in text? How strong is this tendency compared with random word pairs, and compared with near-synonym word pairs?

Experiment: Section 5 describes how we compiled sets of highly contrasting word pairs (including opposites), near-synonym pairs, and random word pairs, and determine the tendency for pairs in each set to co-occur in a corpus.

Findings: Highly contrasting word pairs co-occur significantly more often than both the random word pairs set and also the near-synonyms set. We also find that the average distributional similarity of highly contrasting word pairs is higher than that of synonymous words. The standard deviations of the distributions for the high-contrast set and the synonyms set are large, however, and so the tendency to co-occur is not sufficient to distinguish highly contrasting word pairs from near-synonymous pairs.

(3) On an automatic method for computing lexical contrast:

Research questions: How can the contrast hypothesis and the degree of contrast hypothesis be used to develop an automatic method for identifying contrasting word pairs? How can we automatically generate the list of opposites, which are needed as input for a method relying on the contrast hypothesis?

Proposed Method: Section 6 describes an empirical method for determining the degree of contrast between two words by using the contrast hypothesis, the degree of contrast hypothesis, the structure of a thesaurus, and seed opposite pairs. The use of affixes to generate seed opposite pairs is also described. (This method was first proposed in Mohammad, Dorr, and Hirst [2008].)

(4) On the evaluation of automatic methods of contrast:

Research questions: How accurate are automatic methods at identifying whether one word pair has a higher degree of contrast than another? What is the accuracy of this method in detecting opposites (a notable subset of the contrasting pairs)? How does this accuracy vary for different kinds of opposites?[2] How easy is it for automatic methods to distinguish between opposites and synonyms? How does the proposed method perform when compared with other automatic methods?

Experiments: We conduct three experiments (described in Sections 7.1, 7.2, and 7.3) involving three different data sets and two tasks to answer

2 Note that though linguists have classified opposites into different kinds, we know of no work doing so for contrasts more generally. Thus this particular analysis must be restricted to opposites alone.

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these questions. We compare performance of our method with methods proposed by Lin et al. (2003) and Turney (2008). We automatically generate a new set of 1,296 "most contrasting word" questions to evaluate performance of our method on five different kinds of opposites and across four parts of speech. (The evaluation described in Section 7.1 was first described in Mohammad, Dorr, and Hirst [2008].)

Findings: We find that the proposed measure of lexical contrast obtains high precision and large coverage, outperforming existing methods. Our method performs best on gradable pairs, antipodal pairs, and complementary pairs, but poorly on disjoint opposite pairs. Among different parts of speech, the method performs best on noun pairs, and relatively worse on verb pairs.

All of the data created and compiled as part of this research are summarized in Table 18 (Section 8), and is available for download.[3]

2. Related Work

Charles and Miller (1989) proposed that opposites occur together in a sentence more often than chance. This is known as the **co-occurrence hypothesis**. Paradis, Willners, and Jones (2009) describe further experiments to show how canonical opposites tend to have high textual co-occurrence. Justeson and Katz (1991) gave evidence in support of the hypothesis using 35 prototypical opposites (from an original set of 39 opposites compiled by Deese [1965]) and also with an additional 22 frequent opposites. They also showed that opposites tend to occur in parallel syntactic constructions. All of these pairs were adjectives. Fellbaum (1995) conducted similar experiments on 47 noun, verb, adjective, and adverb pairs (noun–noun, noun–verb, noun–adjective, verb–adverb, etc.) pertaining to 18 concepts (for example, *lose(v)–gain(n)* and *loss(n)–gain(n)*, where *lose(v)* and *loss(n)* pertain to the concept of "failing to have/maintain"). Non-opposite semantically related words also tend to occur together more often than chance, however. Thus, separating opposites from these other classes has proven to be difficult.

Some automatic methods of lexical contrast rely on lexical patterns in text. For example, Lin et al. (2003) used patterns such as "from X to Y" and "either X or Y" to separate opposites from distributionally similar pairs. They evaluated their method on 80 pairs of opposites and 80 pairs of synonyms taken from the *Webster's Collegiate Thesaurus* (Kay 1988). The evaluation set of 160 word pairs was chosen such that it included only high-frequency terms. This was necessary to increase the probability of finding sentences in a corpus where the target pair occurred in one of the chosen patterns. Lobanova, van der Kleij, and Spenader (2010) used a set of Dutch adjective seed pairs to learn lexical patterns commonly containing opposites. The patterns were in turn used to create a larger list of Dutch opposites. The method was evaluated by comparing entries to Dutch lexical resources and by asking human judges to determine whether an automatically found pair is indeed an opposite. Turney (2008) proposed a supervised method for identifying synonyms, opposites, hypernyms, and other lexical-semantic relations between word pairs. The approach learns patterns corresponding to different relations.

3 `http://www.purl.org/net/saif.mohammad/research`.

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Harabagiu, Hickl, and Lacatusu (2006) detected contrasting word pairs for the purpose of identifying contradictions by using WordNet chains—synsets connected by the hypernymy–hyponymy links and exactly one antonymy link. Lucerto, Pinto, and Jimeñez-Salazar (2002) proposed detecting contrasting word pairs using the number of tokens between two words in text and also cue words such as *but*, *from*, and *and*. Unfortunately, they evaluated their method on only 18 word pairs. Neither Harabagiu, Hickl, and Lacatusu nor Lucerto, Pinto, and Jiménez-Salazar determined the degree of contrast between words, and their methods have not been shown to have substantial coverage.

Schwab, Lafourcade, and Prince (2002) created an oppositeness vector for a target word. The closer this vector is to the context vector of the other target word, the more opposite the two target words are. The oppositeness vectors were created by first manually identifying possible opposites and then generating suitable vectors for each using dictionary definitions. The approach was evaluated on only a handful of word pairs.

There is a large amount of work on sentiment analysis and opinion mining aimed at determining the polarity of words (Pang and Lee 2008). For example, Pang, Lee, and Vaithyanathan (2002) detected that adjectives such as *dazzling*, *brilliant*, and *gripping* cast their qualifying nouns positively whereas adjectives such as *bad, cliched,* and *boring* portray the noun negatively. Many of these gradable adjectives have opposites, but these approaches, with the exception of that of Hatzivassiloglou and McKeown (1997), did not attempt to determine pairs of positive and negative polarity words that are opposites. Hatzivassiloglou and McKeown proposed a supervised algorithm that uses word usage patterns to generate a graph with adjectives as nodes. An edge between two nodes indicates either that the two adjectives have the same or opposite polarity. A clustering algorithm then partitions the graph into two subgraphs such that the nodes in a subgraph have the same polarity. They used this method to create a lexicon of positive and negative words, and argued that the method could also be used to detect opposites.

3. The Heterogeneous Nature of Opposites

Opposites, unlike synonyms, can be of different kinds. Many different classifications have been proposed, one of which is given by Cruse (1986) (Chapters 9, 10, and 11). It consists of complementaries (*open–shut, dead–alive*), antonyms (*long–short, slow–fast*) (further classified into polar, overlapping, and equipollent opposites), directional opposites (*up–down, north–south*) (further classified into antipodals, counterparts, and reversives), relational opposites (*husband–wife, predator–prey*), indirect converses (*give–receive, buy–pay*), congruence variants (*huge–little, doctor–patient*), and pseudo opposites (*black–white*).

Various lexical relations have also received attention at the Educational Testing Services, as analogies and "most contrasting word" questions are part of the tests they conduct. They classify opposites into contradictories (*alive–dead, masculine–feminine*), contraries (*old–young, happy-sad*), reverses (*attack–defend, buy–sell*), directionals (*front–back, left–right*), incompatibles (*happy–morbid, frank–hypocritical*), asymmetric contraries (*hot–cool, dry–moist*), pseudo-opposites (*popular–shy, right–bad*), and defectives (*default–payment, limp–walk*) (Bejar, Chaffin, and Embretson 1991).

Keeping in mind the meanings and subtle distinctions between each of these kinds of opposites is not easy even if we provide extensive training to annotators. Because we crowdsource the annotations, and we know that Turkers prefer to spend their time doing the task (and making money) rather than reading lengthy descriptions, we

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focused only on five kinds of opposites that we believed would be easiest to annotate, and which still captured a majority of the opposites:

- **Antipodals** (*top–bottom, start–finish*): Antipodals are opposites in which "one term represents an extreme in one direction along some salient axis, while the other term denotes the corresponding extreme in the other direction" (Cruse 1986, page 225).
- **Complementaries** (*open–shut*, *dead–alive*): The essential characteristic of a pair of complementaries is that "between them they exhaustively divide the conceptual domain into two mutually exclusive compartments, so that what does not fall into one of the compartments must necessarily fall into the other" (Cruse 1986, page 198).
- **Disjoint** (*hot–cold*, *like–dislike*): Disjoint opposites are word pairs that occupy non-overlapping regions in the semantic dimension such that there are regions not covered by either term. This set of opposites includes equipollent adjective pairs (for example, *hot–cold*) and stative verb pairs (for example, *like–dislike*). We refer the reader to Sections 9.4 and 9.7 of Cruse (1986) for details about these sub-kinds of opposites.
- **Gradable opposites** (*long–short, slow–fast*): are adjective-pair or adverb-pair opposites that are gradable, that is, "members of the pair denote degrees of some variable property such as length, speed, weight, accuracy, etc." (Cruse 1986, page 204).
- **Reversibles** (*rise–fall, enter–exit*): Reversibles are opposite verb pairs such that "if one member denotes a change from A to B, its reversive partner denotes a change from B to A" (Cruse 1986, page 226).

It should be noted that there is no agreed-upon number of kinds of opposites. Different researchers have proposed various classifications that overlap to a greater or lesser degree. It is possible that for a certain application or study one may be interested in a kind of opposite not listed here.

4. Crowdsourcing

We used the Amazon Mechanical Turk (AMT) service to obtain annotations for different kinds of opposites. We broke the task into small independently solvable units called HITs (Human Intelligence Tasks) and uploaded them on the AMT Web site.[4] Each HIT had a set of questions, all of which were to be answered by the same person (a *Turker*, in AMT parlance). We created HITs for word pairs, taken from WordNet, that we expected to have some degree of contrast in meaning.

In WordNet, words that are close in meaning are grouped together in a set called a *synset*. If one of the words in a synset is an opposite of another word in a different synset, then the two synsets are called *head synsets* and WordNet records the two words as *direct antonyms* (Gross, Fischer, and Miller 1989)—WordNet regards the terms *opposite* and *antonym* as synonyms. Other word pairs across the two head synsets are called *indirect antonyms*. Because we follow Cruse's definition of antonyms, which requires

4 `https://www.mturk.com/mturk/welcome`.

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Table 1
Target word pairs chosen for annotation. Each term was annotated about eight times.

part of speech	# of word pairs
adverbs	185
adjectives	646
nouns	416
verbs	309
all	**1,556**

antonyms to be gradable adjectives, and because WordNet's direct antonyms include noun, verb, and adverb pairs too, for the rest of the article we will refer to WordNet direct antonyms as **direct opposites** and WordNet indirect antonyms as **indirect opposites**. We will refer to the union of both the direct and indirect opposites simply as **WordNet opposites**. Note that the WordNet opposites are highly contrasting term pairs.

We chose as target pairs all the direct or indirect opposites from WordNet that were also listed in the *Macquarie Thesaurus*. This condition was a mechanism to ignore less-frequent and obscure words, and apply our resources on words that are more common. Additionally, as we will describe subsequently, we use the presence of the words in the thesaurus to help generate Question 1, which we use for quality control of the annotations. Table 1 gives a breakdown of the 1,556 pairs chosen by part of speech.

Because we do not have any control over the educational background of the annotators, we made efforts to phrase questions about the kinds of opposites in a simple and clear manner. Therefore we avoided definitions and long instructions in favor of examples and short questions. We believe this strategy is beneficial even in traditional annotation scenarios.

We created separate questionnaires (HITs) for adjectives, adverbs, nouns, and verbs. A complete example adjective HIT with directions and questions is shown in Figure 1. The adverb, noun, and verb questionnaires had similar questions, but were phrased slightly differently to accommodate differences in part of speech. These questionnaires are not shown here due to lack of space, but all four questionnaires are available for download.[5] The verb questionnaire had an additional question, shown in Figure 2. Because nouns and verbs are not considered gradable, the corresponding questionnaires did not have Q8 and Q9. We requested annotations from eight different Turkers for each HIT.

4.1 The Word Choice Question: Q1

Q1 is an automatically generated word choice question that has a clear correct answer. It helps identify outlier and malicious annotations. If this question is answered incorrectly, then we assume that the annotator does not know the meanings of the target words, and we ignore responses to the remaining questions. Further, as this question makes the annotator think about the meanings of the words and about the relationship between them, we believe it improves the responses for subsequent questions.

The options for Q1 were generated automatically. Each option is a set of four comma-separated words. The words in the answer are close in meaning to both of the target words. In order to create the answer option, we first generated a much larger

5 http://www.purl.org/net/saif.mohammad/research.

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Word-pair: musical × dissonant

Q1. Which set of words is most related to the word pair musical:dissonant?
- useless, surgery, ineffectual, institution
- sequence, episode, opus, composition
- youngest, young, youthful, immature
- consequential, important, importance, heavy

Q2. Do musical and dissonant have some contrast in meaning?
- yes • no

For example, up–down, lukewarm–cold, teacher–student, attack–defend, all have at least some degree of contrast in meaning. On the other hand, clown–down, chilly–cold, teacher–doctor, and attack–rush DO NOT have contrasting meanings.

Q3. Some contrasting words are paired together so often that given one we naturally think of the other. If one of the words in such a pair were replaced with another word of almost the same meaning, it would sound odd. Are musical:dissonant such a pair?
- yes • no

Examples for "yes": tall–short, attack–defend, honest–dishonest, happy–sad.
Examples for "no": tall–stocky, attack–protect, honest–liar, happy–morbid.

Q5. Do musical and dissonant represent two ends or extremes?
- yes • no

Examples for "yes": top–bottom, basement–attic, always–never, all–none, start–finish.
Examples for "no": hot–cold (boiling refers to more warmth than hot and freezing refers to less warmth than cold), teacher–student (there is no such thing as more or less teacher and more or less student), always–sometimes (never is fewer times than sometimes).

Q6. If something is musical, would you assume it is not dissonant, and vice versa?
In other words, would it be unusual for something to be both musical and dissonant?
- yes • no

Examples for "yes": happy–sad, happy–morbid, vigilant–careless, slow–stationary.
Examples for "no": happy–calm, stationary–still, vigilant–careful, honest–truthful.

Q7. If something or someone could possibly be either musical or dissonant, is it necessary that it must be either musical or dissonant? In other words, is it true that for things that can be musical or dissonant, there is no third possible state, except perhaps under highly unusual circumstances?
- yes • no

Examples for "yes": partial–impartial, true–false, mortal–immortal.
Examples for "no": hot–cold (an object can be at room temperature is neither hot nor cold), tall–short (a person can be of medium or average height).

Q8. In a typical situation, if two things or two people are musical, then can one be more musical than the other?
- yes • no

Examples for "yes": quick, exhausting, loving, costly.
Examples for "no": dead, pregnant, unique, existent.

Q9. In a typical situation, if two things or two people are dissonant, can one be more dissonant than the other?
- yes • no

Examples for "yes": quick, exhausting, loving, costly, beautiful.
Examples for "no": dead, pregnant, unique, existent, perfect, absolute.

Figure 1
Example HIT: Adjective pairs questionnaire.

Note: Perhaps "musical × dissonant" might be better written as "musical versus dissonant," but we have kept "×" here to show the reader exactly what the Turkers were given.
Note: Q4 is not shown here, but can be seen in the on-line version of the questionnaire. It was an exploratory question, and it was not multiple choice. Q4's responses have not been analyzed.

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Word-pair: enabling × disabling

Q10. In a typical situation, do the sequence of actions disabling and then enabling bring someone or something back to the original state, AND do the sequence of actions enabling and disabling also bring someone or something back to the original state?

- yes, both ways: the transition back to the initial state makes much sense in both sequences.
- yes, but only one way: the transition back to the original state makes much more sense one way than the other way.
- none of the above

Examples for "yes, both ways": enter–exit, dress–undress, tie–untie, appear–disappear.
Examples for "yes, but only one way": live–die, create–destroy, damage–repair, kill–resurrect.
Examples for "none of the above": leave–exit, teach–learn, attack–defend (attacking and then defending does not bring one back to the original state).

Figure 2
Additional question in the questionnaire for verbs.

source pool of all the words that were in the same thesaurus category as any of the two target words. (Words in the same category are closely related.) Words that had the same stem as either of the target words were discarded. For each of the remaining words, we added their Lesk similarities with the two target words (Banerjee and Pedersen 2003). The four words with the highest sum were chosen to form the answer option.

The three distractor options were randomly selected from the pool of correct answers for all other word choice questions. Finally, the answer and distractor options were presented to the Turkers in random order.

4.2 Post-Processing

The response to a HIT by a Turker is called an **assignment**. We obtained about 12,448 assignments in all (1,556 pairs × 8 assignments each). About 7% of the adjective, adverb, and noun assignments and about 13% of the verb assignments had an incorrect answer to Q1. These assignments were discarded, leaving 1,506 target pairs with three or more valid assignments. We will refer to this set of assignments as the **master set**, and all further analysis in this article is based on this set. Table 2 gives a breakdown of the average number of annotations for each of the target pairs in the master set.

4.3 Prevalence of Different Kinds of Contrasting Pairs

For each question pertaining to every word pair in the master set, we determined the most frequent response by the annotators. Table 3 gives the percentage of word pairs in

Table 2
Number of word pairs and average number of annotations per word pair in the master set.

part of speech	# of word pairs	average # of annotations
adverbs	182	7.80
adjectives	631	8.32
nouns	405	8.44
verbs	288	7.58
all	**1,506**	**8.04**

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Table 3
Percentage of word pairs that received a response of "yes" for the questions in the questionnaire. adj. = adjectives; adv. = adverbs.

		% of word pairs			
Question	answer	adj.	adv.	nouns	verbs
Q2. Do X and Y have some contrast?	yes	99.5	96.8	97.6	99.3
Q3. Are X and Y opposites?	yes	91.2	68.6	65.8	88.8
Q5. Are X and Y at two ends of a dimension?	yes	81.8	73.5	81.1	94.4
Q6. Does X imply not Y?	yes	98.3	92.3	89.4	97.5
Q7. Are X and Y mutually exhaustive?	yes	85.1	69.7	74.1	89.5
Q8. Does X represent a point on some scale?	yes	78.5	77.3	–	–
Q9. Does Y represent a point on some scale?	yes	78.5	70.8	–	–
Q10. Does X undo Y OR does Y undo X?	one way	–	–	–	3.8
	both ways	–	–	–	90.9

Table 4
Percentage of WordNet source pairs that are contrasting, opposite, and "contrasting but not opposite."

category	basis	adj.	adv.	nouns	verbs
contrasting	Q2 yes	99.5	96.8	97.6	99.3
opposites	Q2 yes and Q3 yes	91.2	68.6	60.2	88.9
contrasting, but not opposite	Q2 yes and Q3 no	8.2	28.2	37.4	10.4

the master set that received a most frequent response of "yes." The first column in the table lists the question number followed by a brief description of question. (Note that the Turkers saw only the full forms of the questions, as shown in the example HIT.)

Observe that most of the word pairs are considered to have at least some contrast in meaning. This is not surprising because the master set was constructed using words connected through WordNet's antonymy relation.[6] Responses to Q3 show that not all contrasting pairs are considered opposite, and this is especially the case for adverb pairs and noun pairs. The rows in Table 4 show the percentage of words in the master set that are contrasting (row 1), opposite (row 2), and contrasting but not opposite (row 3).

Responses to Q5, Q6, Q7, Q8, and Q9 (Table 3) show the prevalence of different kinds of relations and properties of the target pairs.

Table 5 shows the percentage of contrasting word pairs that may be classified into the different types discussed in Section 3. Observe that rows for all categories other than the disjoints have percentages greater than 60%. This means that a number of contrasting word pairs can be classified into more than one kind. Complementaries are the most common kind in case of adverbs, nouns, and verbs, whereas antipodals are most common among adjectives. A majority of the adjective and adverb contrasting pairs are gradable, but more than 30% of the pairs are not. Most of the verb pairs are reversives (91.6%). Disjoint pairs are much less common than all the other categories

6 All of the direct antonyms were marked as contrasting by the Turkers. Only a few indirect antonyms were marked as *not contrasting*.

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Table 5
Percentage of contrasting word pairs belonging to various subtypes. The subtype "reversives" applies only to verbs. The subtype "gradable" applies only to adjectives and adverbs.

subtype	basis	adv.	adj.	nouns	verbs
Antipodals	Q2 yes, Q5 yes	82.3	75.9	82.5	95.1
Complementaries	Q2 yes, Q7 yes	85.6	72.0	84.8	98.3
Disjoint	Q2 yes, Q7 no	14.4	28.0	15.2	1.7
Gradable	Q2 yes, Q8 yes, Q9 yes	69.6	66.4	-	-
Reversives	Q2 yes, Q10 both ways	-	-	-	91.6

considered, and they are most prominent among adjectives (28%), and least among verb pairs (1.7%).

4.4 Agreement

People do not always agree on linguistic classifications of terms, and one of the goals of this work was to determine how much people agree on properties relevant to different kinds of opposites. Table 6 lists the breakdown of agreement by target-pair part of speech and question, where agreement is the average percentage of the number of Turkers giving the most-frequent response to a question—the higher the number of Turkers that vote for the majority answer, the higher is the agreement.

Observe that agreement is highest when asked whether a word pair has some degree of contrast in meaning (Q2), and that there is a marked drop when asked if the two words are opposites (Q3). This is true for each of the parts of speech, although the drop is highest for verbs (94.7% to 75.2%).

For Questions 5 through 9, we see varying degrees of agreement—Q6 obtaining the highest agreement and Q5 the lowest. There is marked difference across parts of speech for certain questions. For example, verbs are the easiest to identify (highest agreement for Q5, Q7, and Q8). For Q6, nouns have markedly lower agreement than all other parts of speech—not surprising considering that the set of disjoint opposites is traditionally associated with equipollent adjectives and stative verbs. Adverbs and adjectives have markedly lower agreement scores for Q7 than nouns and verbs.

Table 6
Breakdown of answer agreement by target-pair part of speech and question: For every target pair, a question is answered by about eight annotators. The majority response is chosen as the answer. The ratio of the size of the majority and the number of annotators is indicative of the amount of agreement. The table shows the average percentage of this ratio.

question	adj.	adv.	nouns	verbs	**average**
Q2. Do X and Y have some contrast?	90.7	92.1	92.0	94.7	**92.4**
Q3. Are X and Y opposites?	79.0	80.9	76.4	75.2	**77.9**
Q5. Are X and Y at two ends of a dimension?	70.3	66.5	73.0	78.6	**72.1**
Q6. Does X imply not Y?	89.0	90.2	81.8	88.4	**87.4**
Q7. Are X and Y mutually exhaustive?	70.4	69.2	78.2	88.3	**76.5**
average (Q2, Q3, Q5, Q6, and Q7)	**82.3**	**79.8**	**80.3**	**85.0**	**81.3**
Q8. Does X represent a point on some scale?	77.9	71.5	–	–	**74.7**
Q9. Does Y represent a point on some scale?	75.2	72.0	–	–	**73.6**
Q10. Does X undo Y OR does Y undo X?	–	–	–	73.0	**73.0**

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5. Manifestation of Highly Contrasting Word Pairs in Text

As pointed out earlier, there is work on a small set of opposites showing that opposites co-occur more often than chance (Charles and Miller 1989; Fellbaum 1995). Section 5.1 describes experiments on a larger scale to determine whether highly contrasting word pairs (including opposites) occur together more often than randomly chosen word pairs of similar frequency. The section also compares co-occurrence associations with synonyms.

Research in distributional similarity has found that entries in distributional thesauri tend to also contain terms that are opposite in meaning (Lin 1998; Lin et al. 2003). Section 5.2 describes experiments to determine whether highly contrasting word pairs (including opposites) occur in similar contexts as often as randomly chosen pairs of words with similar frequencies, and whether highly contrasting words occur in similar contexts as often as synonyms.

5.1 Co-Occurrence

In order to compare the tendencies of highly contrasting word pairs, synonyms, and random word pairs to co-occur in text, we created three sets of word pairs: the *high-contrast set*, the *synonyms set*, and the *control set of random word pairs*. The high-contrast set was created from a pool of direct and indirect opposites (nouns, verbs, and adjectives) from WordNet. We discarded pairs that did not meet the following conditions: (1) both members of the pair must be unigrams, (2) both members of the pair must occur in the British National Corpus (BNC) (Burnard 2000), and (3) at least one member of the pair must have a synonym in WordNet. A total of 1,358 word pairs remained, and these form the high-contrast set.

Each of the pairs in the high-contrast set was used to create a synonym pair by choosing a WordNet synonym of exactly one member of the pair.[7] If a word has more than one synonym, then the most frequent synonym is chosen.[8] These 1,358 word pairs form the synonyms set. Note that for each of the pairs in the high-contrast set, there is a corresponding pair in the synonyms set, such that the two pairs have a common term. For example, the pair *agitation* and *calmness* in the high-contrast set has a corresponding pair *agitation* and *ferment* in the synonyms set. We will refer to the common terms (*agitation* in this example) as the **focus words**. Because we also wanted to compare occurrence statistics of the high-contrast set with the random pairs set, we created the control set of random pairs by taking each of the focus words and pairing them with another word in WordNet that has a frequency of occurrence in BNC closest to the term contrasting with the focus word. This is to ensure that members of the pairs across the high-contrast set and the control set have similar unigram frequencies.

We calculated the pointwise mutual information (PMI) (Church and Hanks 1990) for each of the word pairs in the high-contrast set, the random pairs set, and the synonyms set using unigram and co-occurrence frequencies in the BNC. If two words occurred within a window of five adjacent words in a sentence, they were marked as co-occurring (same window as Church and Hanks [1990] used in their seminal work on word–word associations). Table 7 shows the average and standard deviation in each set.

7 If both members of a pair have WordNet synonyms, then one is chosen at random, and its synonym is taken.

8 WordNet lists synonyms in order of decreasing frequency in the SemCor corpus.

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Table 7
Pointwise mutual information (PMI) of word pairs. High positive values imply a tendency to co-occur in text more often than random chance.

	average PMI	standard deviation
high-contrast set	1.471	2.255
random pairs set	0.032	0.236
synonyms set	0.412	1.110

Observe that the high-contrast pairs have a much higher tendency to co-occur than the random pairs control set, and also the synonyms set. The high-contrast set has a large standard deviation, however. A two-sample t-test revealed that the high-contrast set is significantly different from the random set ($p < 0.05$), and also that the high-contrast set is significantly different from the synonyms set ($p < 0.05$).

On average, however, the PMI between a focus word and its contrasting term was lower than the PMI between the focus word and 3,559 other words in the BNC. These were often words related to the focus words, but neither contrasting nor synonymous. Thus, even though a high tendency to co-occur is a feature of highly contrasting pairs, it is not a sufficient condition for detecting them. We use PMI as part of our method for determining the degree of lexical contrast (described in Section 6).

5.2 Distributional Similarity

Charles and Miller (1989) proposed that in most contexts, opposites may be interchanged. The meaning of the utterance will be inverted, of course, but the sentence will remain grammatical and linguistically plausible. This came to be known as the *substitutability hypothesis*. Their experiments did not support this claim, however. They found that given a sentence with the target adjective removed, most people did not confound the missing word with its opposite. Justeson and Katz (1991) later showed that in sentences that contain both members of an adjectival opposite pair, the target adjectives do indeed occur in similar syntactic structures at the phrasal level. Jones et al. (2007) show how the tendency to appear in certain textual constructions such as "from X to Y" and "either X or Y" are indicative of prototypicalness of opposites. Thus, we can formulate the **distributional hypothesis of highly contrasting pairs**: highly contrasting pairs occur in similar contexts more often than non-contrasting word pairs.

We used the same sets of high-contrast pairs, synonyms, and random pairs described in the previous section to gather empirical proof of the distributional hypothesis. We calculated the distributional similarity between each pair in the three sets using Lin's (1998) measure. Table 8 shows the average and standard deviation in each set. Observe that the high-contrast set has a much higher average distributional similarity

Table 8
Distributional similarity of word pairs. The measure proposed in Lin (1998) was used.

	average distributional similarity	standard deviation
opposites set	0.064	0.071
random pairs set	0.036	0.034
synonyms set	0.056	0.057

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than the random pairs control set, and interestingly it is also higher than the synonyms set. Once again, the high-contrast set has a large standard deviation. A two-sample t-test revealed that the high-contrast set is significantly different from both the random set and the synonyms set with a confidence interval of 0.05. This demonstrates that relative to other word pairs, high-contrast pairs tend to occur in similar contexts. We also find that the synonyms set has a significantly higher distributional similarity than the random pairs set ($p < 0.05$). This shows that near-synonymous word pairs also occur in similar contexts (the distributional hypothesis of similarity). Further, a consequence of the large standard deviations in the cases of both high-contrast pairs and synonyms means that distributional similarity alone is not sufficient to determine whether two words are contrasting or synonymous. An automatic method for recognizing contrast will require additional cues. Our method uses PMI and other sources of information described in the next section.

6. Computing Lexical Contrast

In this section, we recapitulate the automatic method for determining lexical contrast that we first proposed in Mohammad, Dorr, and Hirst (2008). Additional details are provided regarding the lexical resources used (Section 6.1) and the method itself (Section 6.2).

6.1 Lexical Resources

Our method makes use of a published thesaurus and co-occurrence information from text. Optionally, it can use opposites listed in WordNet if available. We briefly describe these resources here.

6.1.1 Published Thesauri. Published thesauri, such as *Roget's* and *Macquarie*, divide the vocabulary of a language into about a thousand *categories*. Words within a category are semantically related to each other, and they tend to pertain to a coarse concept. Each category is represented by a category number (unique ID) and a *head word*—a word that best represents the meanings of the words in the category. One may also find opposites in the same category, but this is rare. Words with more than one meaning may be found in more than one category; these represent its coarse senses.

Within a category, the words are grouped into finer units called *paragraphs*. Words in the same paragraph are closer in meaning than those in differing paragraphs. Each paragraph has a *paragraph head*—a word that best represents the meaning of the words in the paragraph. Words in a thesaurus paragraph belong to the same part of speech. A thesaurus category may have multiple paragraphs belonging to the same part of speech. For example, a category may have three noun paragraphs, four verb paragraphs, and one adjective paragraph. We will take advantage of the structure of the thesaurus in our approach.

6.1.2 WordNet. As mentioned earlier, WordNet encodes certain opposites. We found in our experiments (Section 7, subsequently) that more than 90% of contrasting pairs included in Graduate Record Examination (GRE) "most contrasting word" questions are not encoded in WordNet, however. Also, neither WordNet nor any other manually created repository of opposites provides the *degree* of contrast between word pairs. Nevertheless, we investigate the usefulness of WordNet as a source of seed opposites for our approach.

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6.2 Proposed Measure of Lexical Contrast

Our method for determining lexical contrast has two parts: (1) determining whether the target word pair is contrasting or not, and (2) determining the degree of contrast between the words.

6.2.1 Detecting Whether a Target Word Pair is Contrasting. We use the contrast hypothesis to determine whether two words are contrasting. The hypothesis is repeated here:

> *Contrast Hypothesis*: If a pair of words, *A* and *B*, are contrasting, then there is a pair of opposites, *C* and *D*, such that *A* and *C* are strongly related and *B* and *D* are strongly related.

Even if a few exceptions to this hypothesis are found (we are not aware of any), the hypothesis would remain useful for practical applications. We first determine pairs of thesaurus categories that have at least one word in each category that are opposites of each other. We will refer to these categories as **contrasting categories** and the opposite connecting the two categories as the **seed opposite**. Because each thesaurus category is a collection of closely related terms, all of the word pairs across two contrasting categories satisfy the contrast hypothesis, and they are considered to be contrasting word pairs. Note also that words within a thesaurus category may belong to different parts of speech, and they may be related to the seed opposite word through any of the many possible semantic relations. Thus a small number of seed opposites can help identify a large number of contrasting word pairs. We determine whether two categories are contrasting using the three methods described here, which may be used alone or in combination with each other:

Method 1: Using word pairs generated from affix patterns.
Opposites such as *hot–cold* and *dark–light* occur frequently in text, but in terms of type-pairs they are outnumbered by those created using affixes, such as *un-* (*clear–unclear*) and *dis-* (*honest–dishonest*). Further, this phenomenon is observed in most languages (Lyons 1977).

Table 9 lists 15 affix patterns that tend to generate opposites in English. They were compiled by the first author by examining a small list of affixes for the English language.[9] These patterns were applied to all words in the thesaurus that are at least three characters long. If the resulting term was also a valid word in the thesaurus, then the word pair was added to the *affix-generated seed set*. These fifteen rules generated 2,682 word pairs when applied to the words in the *Macquarie Thesaurus*. Category pairs that had these opposites were marked as contrasting. Of course, not all of the word pairs generated through affixes are truly opposites, for example *sect–insect* and *part–impart*. For now, such pairs are sources of error in the system. Manual analysis of these 2,682 word pairs can help determine whether this error is large or small. (We have released the full set of word pairs.) Evaluation results (Section 7) indicate that these seed pairs improve the overall accuracy of the system, however.

Figure 3 presents such an example pair. Observe that categories 360 and 361 have the words *cover* and *uncover*, respectively. Affix pattern 8 from Table 9 produces seed

9 `http://www.englishclub.com/vocabulary/prefixes.htm`.

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Table 9
Fifteen affix patterns used to generate opposites. Here 'X' stands for any sequence of letters common to both words w_1 and w_2.

	affix pattern			
pattern #	**word 1**	**word 2**	**# word pairs**	**example pair**
1	X	*anti*X	41	*clockwise–anticlockwise*
2	X	*dis*X	379	*interest–disinterest*
3	X	*im*X	193	*possible–impossible*
4	X	*in*X	690	*consistent–inconsistent*
5	X	*mal*X	25	*adroit–maladroit*
6	X	*mis*X	142	*fortune–misfortune*
7	X	*non*X	72	*aligned–nonaligned*
8	X	*un*X	833	*biased–unbiased*
9	*l*X	*ill*X	25	*legal–illegal*
10	*r*X	*irr*X	48	*regular–irregular*
11	*im*X	*ex*X	35	*implicit–explicit*
12	*in*X	*ex*X	74	*introvert–extrovert*
13	*up*X	*down*X	22	*uphill–downhill*
14	*over*X	*under*X	52	*overdone–underdone*
15	X*less*	X*ful*	51	*harmless–harmful*
		Total:	2,682	

pair *cover–uncover*, and so the system concludes that the two categories have contrasting meaning. The contrast in meaning is especially strong for the paragraphs *cover* and *expose* because words within these paragraphs are very close in meaning to *cover* and *uncover*, respectively. We will refer to such thesaurus paragraph pairs that have one word each of a seed pair as **prime contrasting paragraphs**. We expect the words across prime contrasting paragraphs to have a high degree of antonymy (for example, *mask* and *bare*), whereas words across other contrasting category paragraphs may have a smaller degree of antonymy as the meaning of these words may diverge significantly from the meanings of the words in the prime contrasting paragraphs (for example, *white lie* and *disclosure*).

Method 2: Using opposites from WordNet.
We compiled a list of 20,611 pairs that WordNet records as direct and indirect opposites. (Recall discussion in Section 4 about direct and indirect opposites.) A large number of these pairs include multiword expressions. Only 10,807 of the 20,611 pairs have both words in the *Macquarie Thesaurus*—the vocabulary used for our experiments. We will refer to them as the **WordNet seed set**. Category pairs that had these opposites were marked as contrasting.

Method 3: Using word pairs in adjacent thesaurus categories.
Most published thesauri, such as *Roget's*, are organized such that categories corresponding to opposing concepts are placed adjacent to each other. For example, in the *Macquarie Thesaurus*: category 369 is about honesty and category 370 is about dishonesty; as shown in Figure 3, category 360 is about hiding and category 361 is about revealing. There are a number of exceptions to this rule, and often a category may be contrasting in meaning to several other categories. Because this was an easy enough heuristic to implement, however, we investigated the usefulness of considering adjacent thesaurus categories

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Category number: 360

Category head: HIDING

1. nouns:

hiding
concealment
covering
screening
...

2. nouns:

cover–up
double blind
smokescreen
white lie
...

3. verbs:

cover
curtain
cushion
mask
...

...

Category number: 361

Category head: REVEALING

1. nouns:

revealing
disclosure
divulgement
impartment
...

2. nouns:

exposure
disinterment
unfoldment
unveiling
...

3. verbs:

expose
bare
flush out
uncover
...

...

Figure 3
Example contrasting category pair. The system identifies the pair to be contrasting through the affix-based seed pair *cover–uncover*. The paragraphs of **cover** and **expose** are referred to as prime contrasting paragraphs. Paragraph heads are shown in bold italic.

as contrasting. We will refer to this as the *adjacency heuristic*. Note that this method of determining contrasting categories does not explicitly identify a seed opposite, but one can assume the head words of these category pairs as the seed opposites.

To determine how accurate the adjacency heuristic is, the first author manually inspected adjacent thesaurus categories in the *Macquarie Thesaurus* to determine which of them were indeed contrasting. Because a category, on average, has about a hundred words, the task was made less arduous by representing each category by just the first ten words listed in it. This way it took only about five hours to manually determine that 209 pairs of the 811 adjacent Macquarie category pairs were contrasting. Twice, it was found that category number X was contrasting not just to category number X+1 but also to category number X+2: category 40 (ARISTOCRACY) has a meaning that contrasts that of category 41 (MIDDLE CLASS) as well as category 42 (WORKING CLASS); category 542 (PAST) contrasts with category 543 (PRESENT) as well as category 544 (FUTURE). Both these X – (X+2) pairs are also added to the list of manually annotated contrasting categories.

6.2.2 Computing the Degree of Contrast Between Two Words. Charles and Miller (1989) and Fellbaum (1995) argued that opposites tend to co-occur more often than random chance. Murphy and Andrew (1993) claimed that the greater-than-chance co-occurrence of opposites is because together they convey contrast well, which is rhetorically useful. We showed earlier in Section 5.1 that highly contrasting pairs (including opposites) co-occur more often than randomly chosen pairs. All of these support the degree of contrast hypothesis stated earlier in the introduction:

> *Degree of Contrast Hypothesis*: If a pair of words, *A* and *B*, are contrasting, then their degree of contrast is proportional to their tendency to co-occur in a large corpus.

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We used PMI to capture the tendency of word–word co-occurrence. We collected these co-occurrence statistics from the Google *n*-gram corpus (Brants and Franz 2006), which was created from a text collection of over one trillion words. Words that occurred within a window of five words were considered to be co-occurring.

We expected that some features may be more accurate than others. If multiple features give evidence towards opposing information, then it is useful for the system to know which feature is more reliable. Therefore, we held out some data from the evaluation data described in Section 7.1 as the development set. Experiments on the development set showed that contrasting words may be placed in three bins corresponding to the amount of reliability of the source feature: high, medium, or acceptable.

- **High reliability (Class I):** target words that belong to adjacent thesaurus categories. For example, all the word pairs across categories 360 and 361, shown in Figure 3. Examples of Class I contrasting word pairs from the development set include *graceful–ungainly, fortunate–hapless, obese–slim,* and *effeminate–virile*. (Note, there need not be any affix or WordNet seed pairs across adjacent thesaurus categories for these word pairs to be marked Class I.) As expected, if we use only those adjacent categories that were manually identified to be contrasting (as described in Section 6.2.1, Method 3), then the system obtains even better results than those obtained using all adjacent thesaurus categories. (Experiments and results shown in Section 7.1).
- **Medium reliability (Class II):** target words that are not Class I contrasting pairs, but belong to one paragraph each of a prime contrasting paragraph. For example, all the word pairs across the paragraphs of *sympathetic* and *indifferent*. See Figure 4. Examples of Class II contrasting word pairs from the development set include *altruism–avarice, miserly–munificent, accept–repudiate,* and *improper–prim*.
- **Acceptable reliability (Class III):** target words that are not Class I or Class II contrasting pairs, but occur across contrasting category pairs. For example, all word pairs across categories 423 and 230 except those that have one word each from the paragraphs of *sympathetic* and *indifferent*. See Figure 4. Examples of Class III contrasting word pairs from the development set include *pandemonium–calm, probity–error, artifice–sincerity,* and *hapless–wealthy*.

Even with access to very large textual data sets, there is always a long tail of words that occur so few times that there is not enough co-occurrence information for them. Thus we assume that all word pairs in Class I have a higher degree of contrast than all word pairs in Class II, and that all word pairs in Class II have a higher degree of contrast than the pairs in Class III. If two word pairs belong to the same class, then we calculate their tendency to co-occur with each other in text to determine which pair is more contrasting. All experiments in the evaluation section ahead follow this method.

6.2.3 Lexicon of Contrasting Word Pairs. Using the method described in the previous sections, we generated a lexicon of word pairs pertaining to Class I and Class II. The lexicon has 6.3 million contrasting word pairs, about 3.5 million of which belong to Class I and about 2.8 million to Class II. Class III pairs are even more numerous and, given a word pair, our algorithm checked whether it is a Class III pair, but we did not

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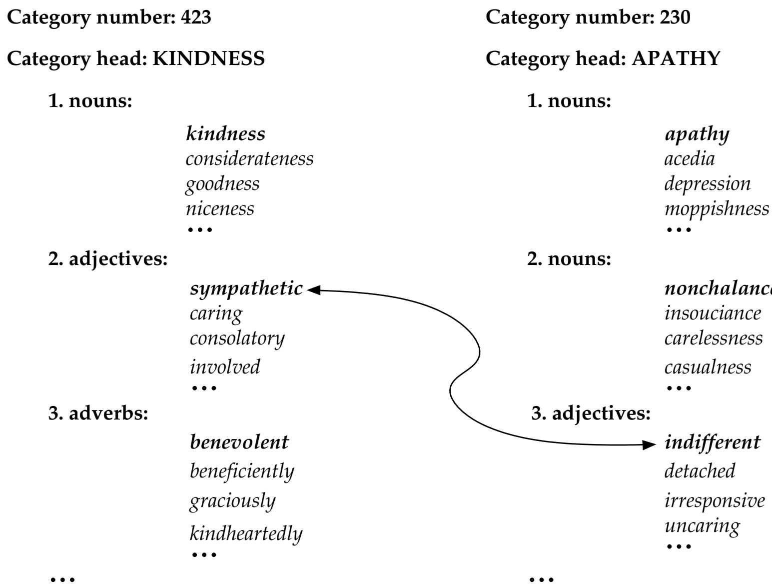

Figure 4
Example contrasting category pair that has Class II and Class III contrasting pairs. The system identifies the pair to be contrasting through the affix-based seed pair *caring* (second word in paragraph 2 or category 423) and *uncaring* (fourth word in paragraph 3 or category 230). The paragraphs of *sympathetic* and *indifferent* are therefore the prime contrasting paragraphs and so all word pairs that have one word each from these two paragraphs are Class II contrasting pairs. All other pairs formed by taking one word each from the two contrasting categories are the Class III contrasting pairs. Paragraph heads are shown in bold italic.

create a complete set of all Class III contrasting pairs. Class I and II lexicons are available for download and summarized in Table 18.

7. Evaluation

We evaluate our algorithm on two different tasks and four data sets. Section 7.1 describes experiments on solving existing GRE "choose the most contrasting word" questions (a recapitulation of the evaluation reported in Mohammad, Dorr, and Hirst [2008]). Section 7.2 describes experiments on solving newly created "choose the most contrasting word" questions specifically designed to determine performance on different kinds of opposites. And lastly, Section 7.3 describes experiments on two different data sets where the goal is to identify whether a given word pair is synonymous or antonymous.

7.1 Solving GRE's "Choose the Most Contrasting Word" Questions

The GRE is a test taken by thousands of North American graduate school applicants. The test is administered by Educational Testing Service (ETS). The Verbal Reasoning section of GRE is designed to test verbal skills. Until August 2011, one of its sections had a set of questions pertaining to word-pair contrast. Each question had a target word and four or five alternatives, or option words. The objective was to identify the alternative which was most contrasting with respect to the target. For example, consider:

adulterate: a. *renounce* b. *forbid* c. *purify* d. *criticize* e. *correct*

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Here the target word is *adulterate*. One of the alternatives provided is *correct*, which as a verb has a meaning that contrasts with that of *adulterate*; *purify*, however, has a greater degree of contrast with *adulterate* than *correct* does and must be chosen in order for the instance to be marked as correctly answered. ETS referred to these questions as "antonym questions," where the examinees had to "choose the word most nearly opposite" to the target. Most of the target–answer pairs are not gradable adjectives, however, and because most of them are not opposites either, we will refer to these questions as *"choose the most contrasting word" questions* or *contrast questions* for short.

Evaluation on this data set tests whether the automatic method is able to identify not just opposites but also those pairs that are not opposites but that have some degree of semantic contrast. Notably, for these questions, the method must be able to identify that one word pair has a higher degree of contrast than all others, even though that word pair may not necessarily be an opposite.

7.1.1 Data. A Web search for large sets of contrast questions yielded two independent sets of questions designed to prepare students for the GRE. The first set consists of 162 questions. We used this set while we were developing our lexical contrast algorithm described in Section 4. Therefore, we will refer to it as the *development set*. The development set helped determine which features of lexical contrast were more reliable than others. The second set has 1,208 contrast questions. We discarded questions that had a multiword target or alternative. After removing duplicates we were left with 790 questions, which we used as the unseen *test set*. This data set was used (and seen) only after our algorithm for determining lexical contrast was frozen.

Interestingly, the data contains many instances that have the same target word used in different senses. For example:

1. ***obdurate:***	a. *meager*	b. *unsusceptible*	c. *right*	d. *tender*	e. *intelligent*
2. ***obdurate:***	a. *yielding*	b. *motivated*	c. *moribund*	d. *azure*	e. *hard*
3. ***obdurate:***	a. *transitory*	b. *commensurate*	c. *complaisant*	d. *similar*	e. *laconic*

In (1), *obdurate* is used in the sense of HARDENED IN FEELINGS and is most contrasting with *tender*. In (2), it is used in the sense of RESISTANT TO PERSUASION and is most contrasting with *yielding*. In (3), it is used in the sense of PERSISTENT and is most contrasting with *transitory*.

The data sets also contain questions in which one or more of the alternatives is a near-synonym of the target word. For example:

astute: a. *shrewd* b. *foolish* c. *callow* d. *winning* e. *debating*

Observe that *shrewd* is a near-synonym of *astute*. The word most contrasting with *astute* is *foolish*. A manual check of a randomly selected set of 100 test-set questions revealed that, on average, one in four had a near-synonym as one of the alternatives.

7.1.2 Results. Table 10 presents results obtained on the development and test data using two baselines, a re-implementation of the method described in Lin et al. (2003), and variations of our method. Some of the results are for systems that refrain from

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Table 10
Results obtained on contrast questions. The best performing system and configuration are shown in bold.

	development data			test data		
	P	R	F	P	R	F
Baselines:						
a. random baseline	0.20	0.20	0.20	0.20	0.20	0.20
b. WordNet antonyms	0.23	0.23	0.23	0.23	0.23	0.23
Related work:						
a. Lin et al. (2003)	0.23	0.23	0.23	0.24	0.24	0.24
Our method:						
a. affix-generated pairs as seeds	0.72	0.53	0.61	0.71	0.51	0.59
b. WordNet antonyms as seeds	0.79	0.52	0.63	0.72	0.49	0.58
c. both seed sets (a + b)	0.77	0.65	0.70	0.72	0.58	0.64
d. adjacency heuristic only	0.81	0.43	0.56	0.83	0.44	0.57
e. manual annotation of adjacent categories	0.88	0.41	0.56	0.87	0.41	0.55
f. affix seed set and adjacency heuristic (a + d)	0.75	0.60	0.67	0.76	0.60	0.67
g. both seed sets and adjacency heuristic (a + b + d)	0.76	0.66	0.70	0.76	0.63	0.69
h. affix seed set and annotation of adjacent categories (a + e)	0.79	0.63	0.70	0.78	0.60	0.68
i. **both seed sets and annotation of adjacent categories (a + b + e)**	**0.79**	**0.66**	**0.72**	**0.77**	**0.63**	**0.69**

attempting questions for which they do not have sufficient information. We therefore report precision (P), recall (R), and balanced F-score (F).

$$P = \frac{\text{\# of questions answered correctly}}{\text{\# of questions attempted}} \tag{1}$$

$$R = \frac{\text{\# of questions answered correctly}}{\text{\# of questions}} \tag{2}$$

$$F = \frac{2 \times P \times R}{P + R} \tag{3}$$

Baselines. If a system randomly guesses one of the five alternatives with equal probability (*random baseline*), then it obtains an accuracy of 0.2. A system that looks up the list of WordNet antonyms (10,807 pairs) to solve the contrast questions is our second baseline. That obtained the correct answer in only 5 instances of the development set (3.09% of the 162 instances) and 25 instances of the test set (3.17% of the 790 instances), however. Even if the system guesses at random for all other instances, it attains only a modest improvement over the random baseline (see row *b*, under "*Baselines*," in Table 10).

Re-implementation of related work. In order to estimate how well the method of Lin et al. (2003) performs on this task, we re-implemented their method. For each closest-antonym question, we determined frequency counts in the Google *n*-gram corpus for the phrases "from ⟨target word⟩ to ⟨known correct answer⟩," "from ⟨known correct answer⟩ to ⟨target word⟩," "either ⟨target word⟩ or ⟨known correct answer⟩," and "either ⟨known correct answer⟩ or ⟨target word⟩." We then summed up the four counts for each contrast question. This resulted in non-zero counts for only 5 of the 162 instances in the development set (3.09%), and 35 of the 790 instances in the test set (4.43%). Thus, these patterns fail to cover a vast majority of closest-antonyms, and even if the

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system guesses at random for all other instances, it attains only a modest improvement over the baseline (see row *a*, under "Related work," in Table 10).

Our method. Table 10 presents results obtained on the development and test data using different combinations of the seed sets and the adjacency heuristic. The best performing system is marked in bold. It has significantly higher precision and recall than that of the method proposed by Lin et al. (2003), with 95% confidence according to the Fisher Exact Test (Agresti 1990).

We performed experiments on the development set first, using our method with configurations described in rows a, b, and d. These results showed that marking adjacent categories as contrasting has the highest precision (0.81), followed by using WordNet seeds (0.79), followed by the use of affix rules to generate seeds (0.72). This allowed us to determine the relative reliability of the three features as described in Section 6.2.2. We then froze all system development and ran the remaining experiments, including those on the test data.

Observe that all of the results shown in Table 10 are well above the random baseline of 0.20. Using only the small set of 15 affix rules, the system performs almost as well as when it uses 10,807 WordNet opposites. Using both the affix-generated and the WordNet seed sets, the system obtains markedly improved precision and coverage. Using only the adjacency heuristic gave precision values (upwards of 0.8) with substantial coverage (attempting more than half of the questions). Using the manually identified contrasting adjacent thesaurus categories gave precision values just short of 0.9. The best results were obtained using both seed sets and the contrasting adjacent thesaurus categories (F-scores of 0.72 and 0.69 on the development and test set, respectively).

In order to determine whether our method works well with thesauri other than the *Macquarie Thesaurus*, we determined performance of configurations a, b, c, d, f, and h using the 1911 U.S. edition of the *Roget's Thesaurus*, which is available freely in the public domain.[10] The results were similar to those obtained using the *Macquarie Thesaurus*. For example, configuration g obtained a precision of 0.81, recall of 0.58, and F-score of 0.68 on the test set. It may be possible to obtain even better results by combining multiple lexical resources; that is left for future work. The remainder of this article reports results obtained with the *Macquarie Thesaurus*; the 1911 vocabulary is less suited for practical use in the 21st century.

7.1.3 Discussion. These results show that our method performs well on questions designed to be challenging for humans. In tasks that require higher precision, using only the contrasting adjacent categories is best, whereas in tasks that require both precision and coverage, the seed sets may be included. Even when both seed sets were included, only four instances in the development set and twenty in the test set had target–answer pairs that matched a seed opposite pair. For all remaining instances, the approach had to generalize to determine the most contrasting word. This also shows that even the seemingly large number of direct and indirect antonyms from WordNet (more than 10,000) are by themselves insufficient.

The comparable performance obtained using the affix rules alone suggests that even in languages that do not have a WordNet-like resource, substantial accuracies may be obtained. Of course, improved results when using WordNet antonyms as well suggests that the information they provide is complementary.

10 http://www.gutenberg.org/ebooks/10681.

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Error analysis revealed that at times the system failed to identify that a category pertaining to the target word contrasted with a category pertaining to the answer. Additional methods to identify seed opposite pairs will help in such cases. Certain other errors occurred because one or more alternatives other than the official answer were also contrasting with the target. For example, one of the questions has *chasten* as the target word. One of the alternatives is *accept*, which has some degree of contrast in meaning to the target. Another alternative, *reward*, has an even higher degree of contrast with the target, however. In this instance, the system erred by choosing *accept* as the answer.

7.2 Determining Performance of Automatic Method on Different Kinds of Opposites

The previous section showed the overall performance of our method. The performance of a method may vary significantly on different subsets of data, however. In order to determine performance on different kinds of opposites, we generated new contrast questions from the crowdsourced term pairs described in Section 4. Note that for solving contrast questions with this data set, again the method must be able to identify that one word pair has a higher degree of contrast than the other pairs; unlike the previous section, however, here the correct answer is often an opposite of the target.

7.2.1 Generating Contrast Questions. For each word pair from the list of WordNet opposites, we chose one word randomly to be the target word, and the other as one of its candidate options. Four other candidate options were chosen from Lin's distributional thesaurus (Lin 1998).[11] An entry in the distributional thesaurus has a focus word and a number of other words that are distributionally similar to the focus word. The words are listed in decreasing order of similarity. Note that these entries include not just near-synonymous words but also at times contrasting words because contrasting words tend to be distributionally similar (Lin et al. 2003).

For each of the target words in our contrast questions, we chose the four distributionally closest words from Lin's thesaurus to be the distractors. If a distractor had the same first three letters as the target word or the correct answer, then it was replaced with another word from the distributional thesaurus. This ad hoc filtering criterion is effective at discarding distractors that are morphological variants of the target or the answer. For example, if the target word is *adulterate*, then words such as *adulterated* and *adulterates* will not be included as distractors even if they are listed as closely similar terms in the distributional thesaurus.

We place the four distractors and the correct answer in random order. Some of the WordNet opposites were not listed in Lin's thesaurus, and the corresponding question was not generated. In all, 1,269 questions were generated. We created subsets of these questions corresponding to the different kinds of opposites and also corresponding to different parts of speech. Because a word pair may be classified as more than one kind of opposite, the corresponding question may be part of more than one subset.

7.2.2 Experiments and Results. We applied our method of lexical contrast to solve the complete set of 1,269 questions and also the various subsets. Because this test set is

11 `http://webdocs.cs.ualberta.ca/~lindek/downloads.htm`.

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Table 11
Percentage of contrast questions correctly answered by the automatic method, where different question sets correspond to target–answer pairs of *different kinds*. The automatic method did not use WordNet seeds for this task. The results shown for 'ALL' are micro-averages, that is, they are the results for the master set of 1,269 contrast questions.

	# instances	P	R	F
Antipodals	1,044	0.95	0.84	0.89
Complementaries	1,042	0.95	0.83	0.89
Disjoint	228	0.81	0.59	0.69
Gradable	488	0.95	0.85	0.90
Reversives	203	0.93	0.74	0.82
ALL	1,269	0.93	0.79	0.85

created from WordNet opposites, we applied the algorithm without the use of WordNet seeds (no WordNet information was used by the method).

Table 11 shows the precision (P), recall (R), and F-score (F) obtained by the method on the data sets corresponding to different kinds of opposites. The column '# instances' shows the number of questions in each of the data sets. The performance of our method on the complete data set is shown in the last row ALL. Observe that the F-score of 0.85 is markedly higher than the score obtained on the GRE-preparatory questions. This is expected because the GRE questions involved vocabulary from a higher reading level, and included carefully chosen distractors to confuse the examinee. The automatic method obtains highest F-score on the data sets of gradable adjectives (0.90), antipodals (0.89), and complementaries (0.89). The precisions and recalls for these opposites are significantly higher than those of disjoint opposites. The recall for reversives is also significantly lower than that for the gradable adjectives, antipodals, and complementaries, but precision on reversives is quite good (0.93).

Table 12 shows the precision, recall, and F-score obtained by the method on the the data sets corresponding to different parts of speech. Observe that performances on all parts of speech are fairly high. The method deals with adverb pairs best (F-score of 0.89), and the lowest performance is for verbs (F-score of 0.80). The differences in precision values between various parts of speech are not significant. The recall obtained on the adverbs is significantly higher than that obtained on adjectives, however, and the recall on adjectives is significantly higher than that obtained on verbs. The difference between the recalls on adverbs and nouns is not significant. We used the Fisher Exact Test and a confidence interval of 95% for all significance testing reported in this section.

Table 12
Percentage of contrast questions correctly answered by the automatic method, where different question sets correspond to *different parts-of-speech*.

	# instances	P	R	F
Adjectives	551	0.92	0.79	0.85
Adverbs	165	0.95	0.84	0.89
Nouns	330	0.93	0.81	0.87
Verbs	226	0.93	0.71	0.80
ALL	1,269	0.93	0.79	0.85

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7.3 Distinguishing Synonyms from Opposites

Our third evaluation follows that of Lin et al. (2003) and Turney (2008). We developed a system for automatically distinguishing synonyms from opposites, and applied it to two data sets. The approach and experiments are described herein.

7.3.1 Data. Lin et al. (2003) compiled 80 pairs of synonyms and 80 pairs of opposites from the *Webster's Collegiate Thesaurus* (Kay 1988) such that each word in a pair is also in their list of the 50 distributionally most similar words of the other. (Distributional similarity was calculated using the algorithm proposed by Lin et al. [1998].) Turney (2008) compiled 136 pairs of words (89 opposites and 47 synonyms) from various Web sites for learners of English as a second language; the objective for the learners is to identify whether the words in a pair are opposites or synonyms of each other. The goals of this evaluation are to determine whether our automatic method can distinguish opposites from near-synonyms, and to compare our method with the closest related work on an evaluation task for which published results are already available.

7.3.2 Method. The core of our method is this:

1. Word pairs that occur in the same thesaurus category are close in meaning and so are marked as synonyms.
2. Word pairs that occur in contrasting thesaurus categories or paragraphs (as described in Section 6.2.1 above) are marked as opposites.

Even though opposites often occur in different thesaurus categories, they can sometimes also be found in the same category, however. For example, the word *ascent* is listed in the *Macquarie Thesaurus* categories of 49 (CLIMBING) and 694 (SLOPE), whereas the word *descent* is listed in the categories 40 (ARISTOCRACY), 50 (DROPPING), 538 (PARENTAGE), and 694 (SLOPE). Observe that *ascent* and *descent* are both listed in the same category 694 (SLOPE), which makes sense here because both words are pertinent to the concept of slope. On the other hand, two separate clues independently inform our system that the words are opposites of each other: (1) Category 49 has the word *upwardness* in the same paragraph as *ascent*, and category 50 has the word *downwardness* in the same paragraph as *descent*. The 13th affix pattern from Table 9 (*up*X and *down*X) indicates that the two thesaurus paragraphs have contrasting meaning. Thus, *ascent* and *descent* occur in prime contrasting thesaurus paragraphs. (2) One of the *ascent* categories (49) is adjacent to one of the *descent* categories (50), and further this adjacent category pair has been manually marked as contrasting.

Thus the words in a pair may be deemed both synonyms and opposites simultaneously by our methods of determining synonyms and opposites, respectively. Some of the features we use to determine opposites were found to be more precise (e.g., words listed in adjacent categories) than others (e.g., categories identified as contrasting based on affix and WordNet seeds), however. Thus we apply the following rules as a decision list: If one rule fires, then the subsequent rules are ignored.

1. **Rule 1 (high confidence for opposites):** If the words in a pair occur in adjacent thesaurus categories, then they are marked as opposites.
2. **Rule 2 (high confidence for synonyms):** If both the words in a pair occur in the same thesaurus category, then they are marked as synonyms.

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3. **Rule 3 (medium confidence for opposites):** If the words in a pair occur in prime contrasting thesaurus paragraphs, as determined by an affix-based or WordNet seed set, then they are marked as opposites.

If a word pair is not tagged as synonym or opposite: (a) the system can refrain from attempting an answer (this will attain high precision), or (b) the system can randomly guess the lexical relation (this will obtain 50% accuracy for the pairs), or (c) it could mark all remaining word pairs with the predominant lexical relation in the data (this will obtain an accuracy proportional to the skew in distribution of opposites and synonyms). For example, if after step 3, the system finds that 70% of the marked word pairs were tagged opposites, and 30% as synonyms, then it could mark every hitherto untagged word pair (word pair for which it has insufficient information) as opposites. We implemented all three variants. Note that option (b) is indeed expected to perform poorly compared to option (c), but we include it as part of our evaluation to measure usefulness of option (c).

7.3.3 Results and Discussion. Table 13 shows the precision (P), recall (R), and balanced F-score (F) of various systems and baselines in identifying synonyms and opposites from the data set described in Lin et al. (2003). We will refer to this data set as LZQZ (the first letters of the authors' last names).

If a system guesses at random (random baseline) it will obtain an accuracy of 50%. Choosing opposites (or synonyms) as the predominant class also obtains an accuracy of 50% because the data set has an equal number of opposites and synonyms. Published results on LZQZ (Lin et al. 2003) are shown here again for convenience. The results obtained with our system and the three variations on handling word pairs for which it does not have enough information are shown in the last three rows. The precision of our method in configuration (a) is significantly higher than that of Lin et al. (2003), with 95% confidence according to the Fisher Exact Test (Agresti 1990). Because precision and recall are the same for configuration (b) and (c), as well as for the methods described in Lin et al. (2003) and Turney (2011), we can also refer to these results simply as accuracy.

Table 13
Results obtained on the synonym-or-opposite questions in LZQZ. The best performing systems are marked in bold. The difference in precision and recall of method by Lin et al. (2003) and our method in configurations (b) and (c) is not statistically significant.

	P	R	F
Baselines:			
a. random baseline	0.50	0.50	0.50
b. supervised most-frequent baseline†	0.50	0.50	0.50
Related work:			
a. **Lin et al. (2003)**	**0.90**	**0.90**	**0.90**
b. Turney (2011)	0.82	0.82	0.82
Our method: if no information			
a. refrain from guessing	0.98	0.78	0.87
b. **make random guess**	**0.88**	**0.88**	**0.88**
c. **mark the predominant class**‡	**0.87**	**0.87**	**0.87**

†This data set has an equal number of opposites and synonyms. Results reported are when choosing opposites as the predominant class.

‡The system concluded that opposites were slightly more frequent than synonyms.

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Table 14
Results obtained on the synonym-or-opposite questions in TURN. The best performing systems are marked in bold.

	P	R	F
Baselines			
a. random baseline	0.50	0.50	0.50
b. supervised most-frequent baseline†	0.65	0.65	0.65
Related work			
a. Turney (2008)	0.75	0.75	0.75
b. Lin et al. (2003)	0.35	0.35	0.35
Our method: if no information			
a. refrain from guessing	0.97	0.69	0.81
b. **make random guess**	**0.84**	**0.84**	**0.84**
c. **mark the predominant class**‡	**0.90**	**0.90**	**0.90**

† About 65.4% of the pairs in this data set are opposites. So this row reports baseline results when choosing opposites as the predominant class.
‡ The system concluded that opposites were much more frequent than synonyms.

We found that the differences in accuracies between the method of Lin et al. (2003) and our method in configurations (b) and (c) are *not* statistically significant. The method by Lin et al. (2003) and our method in configuration (b) have significantly higher accuracy than the method described in Turney (2011), however. The lexical contrast features used in configurations (a), (b), and (c) correspond to row i in Table 10. The next subsection presents an analysis of the usefulness of the different features listed in Table 10.

Observe that when our method refrains from guessing in case of insufficient information, it obtains excellent precision (0.98), while still providing very good coverage (0.78). As expected, the results obtained with (b) and (c) do not differ much from each other because the data set has an equal number of synonyms and opposites. (Note that the system was not privy to this information.) After step 3 of the algorithm, however, the system had marked 65 pairs as opposites and 63 pairs as synonyms, and so it concluded that opposites are slightly more dominant in this data set and therefore the guess-predominant-class variant marked all previously unmarked pairs as opposites.

It should be noted that the LZQZ data set was chosen from a list of high-frequency terms. This was necessary to increase the probability of finding sentences in a corpus where the target pair occurred in one of the chosen patterns proposed by Lin et al. (2003). As shown in Table 10, the Lin et al. (2003) patterns have a very low coverage otherwise. Further, the test data compiled by Lin et al. only had opposites whereas the contrast questions had many contrasting word pairs that were not opposites.

Table 14 shows results on the data set described in Turney (2008). We will refer to this data set as TURN. The supervised baseline of always guessing the most frequent class (in this case, opposites), will obtain an accuracy of 65.4% ($P = R = F = 0.654$).

Turney (2008) obtains an accuracy of 75% using a supervised method and 10-fold cross-validation. A re-implementation of the method proposed by Lin et al. (2003) as described in Section 7.1.3 did not recognize any of the word pairs in TURN as opposites; that is, none of the word pairs in TURN occurred in the Google n-gram corpus in patterns used by Lin et al. (2003). Thus it marked all words in TURN as synonyms. The results obtained with our method are shown in the last three rows. The precision and recall of our method in configurations (b) and (c) are significantly higher than those

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obtained by the methods by Turney (2008) and Lin et al. (2003), with 95% confidence according to the Fisher Exact Test (Agresti 1990).

Observe that once again our method, especially the variant that refrains from guessing in case of insufficient information, obtains excellent precision (0.97), while still providing good coverage (0.69). Also observe that results obtained by guessing the predominant class (method (c)) are markedly better than those obtained by randomly guessing in case of insufficient information (method (b)). This is because, as mentioned earlier, the distribution of opposites and synonyms is somewhat skewed in this data set (65.4% of the pairs are opposites). Of course, again the system was not privy to this information, but method (a) marked 58 pairs as opposites and 39 pairs as synonyms. Therefore, the system concluded that opposites are more dominant and method (c) marked all previously unmarked pairs as opposites, obtaining an accuracy of 90%.

Recall that in Section 7.3.2 we described how opposite pairs may occasionally be listed in the same thesaurus category because the category may be pertinent to both words. For 12 of the word pairs in the Lin et al. data and 3 of the word pairs in the Turney data, both words occurred together in the same thesaurus category, and yet the system marked them as opposites because they occurred in adjacent thesaurus categories (Class I). For 11 of the 12 pairs from LZQZ and for all 3 of the TURN pairs, this resulted in the correct answer. These pairs are shown in Table 15. By contrast, only one of the term pairs in this table occurred in one of Lin's patterns of oppositeness, and was thus the only one correctly identified by their method as a pair of opposites.

It should also be noted that a word may have multiple meanings such that it may be synonymous to a word in one sense and opposite to it in another sense. Such pairs are also expected to be marked as opposites by our system. Two such pairs in the Turney (2008) data are: *fantastic–awful* and *terrific–terrible*. The word *awful* can mean INSPIRING AWE (and so close to the meaning of *fantastic* in some contexts), and also EXTREMELY DISAGREEABLE (and so opposite to *fantastic*). The word *terrific* can mean FRIGHTFUL (and so close to the meaning of *terrible*), and also UNUSUALLY FINE (and so opposite to *terrible*). Such pairs are probably not the best synonym-or-opposite questions. Faced with these questions, however, humans probably home in on the dominant senses of

Table 15
Pairs from LZQZ and TURN that have at least one category in common but are still marked as opposites by our method.

LZQZ			TURN		
word 1	**word 2**	**official solution**	**word 1**	**word 2**	**official solution**
amateur	professional	opposite	fantastic	awful	opposite
ascent	descent	opposite	dry	wet	opposite
back	front	opposite	terrific	terrible	opposite
bottom	top	opposite			
broadside	salvo	synonym			
entrance	exit	opposite			
heaven	hell	opposite			
inside	outside	opposite			
junior	senior	opposite			
lie	truth	opposite			
majority	minority	opposite			
nadir	zenith	opposite			
strength	weakness	opposite			

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Table 16
Results for individual components as well as certain combinations of components on the synonym-or-opposite questions in LZQZ. The best performing configuration is shown in bold.

	P	R	F
Baselines:			
a. random baseline	0.50	0.50	0.50
b. supervised most-frequent baseline†	0.50	0.50	0.50
Our methods:			
a. affix-generated seeds only	0.86	0.54	0.66
b. WordNet seeds only	0.88	0.65	0.75
c. both seed sets (a + b)	0.88	0.65	0.75
d. adjacency heuristic only	0.95	0.74	0.83
e. manual annotation of adjacent categories	0.98	0.74	0.84
f. affix seed set and adjacency heuristic (a + d)	0.95	0.75	0.84
g. both seed sets and adjacency heuristic (a + b + d)	0.95	0.78	0.86
h. affix seed set and annotation of adjacent categories (a + e)	0.98	0.77	0.86
i. **both seed sets and annotation of adjacent categories (a + b + e)**	**0.98**	**0.78**	**0.87**

†This data set has equal number of opposites and synonyms, so either class can be chosen to be predominant. Baseline results shown here are for choosing opposites as the predominant class.

the target words to determine an answer. For example, in modern-day English *terrific* is used more frequently in the sense of UNUSUALLY FINE than the sense of FRIGHTFUL, and so most people will say that *terrific* and *terrible* are opposites (in fact that is the solution provided with these data).

7.3.4 Analysis. We carried out additional experiments to determine how useful individual components of our method were in solving the synonym-or-opposite questions. The results on LZQZ are shown in Table 16 and the results on TURN are shown in Table 17. These results are for the case when the system refrains from guessing in case of insufficient information. The rows in the tables correspond to the rows in Table 10 shown earlier that gave results on the contrast questions.

Observe that the affix-generated seeds give a marked improvement over the baselines, and that knowing which categories are contrasting (either from the adjacency heuristic or manual annotation of adjacent categories) proves to be the most useful feature. Also note that even though manual annotation and WordNet seeds eventually lead to the best results (F = 0.87 for LZQZ and F = 0.81 for TURN), using only the adjacency heuristic and the affix-generated seeds gives competitive results (F = 0.84 for the Lin set and F = 0.78 for the Turney set). We are interested in developing methods to make the approach cross-lingual, so that we can use a thesaurus from one language (say, English) to compute lexical contrast in a resource-poor target language.

The precision of our method is very good (>0.95). Thus future work will be aimed at improving recall. This can be achieved by developing methods to generate more seed opposites. This is also an avenue through which some of the pattern-based approaches (such as the methods described by Lin et al. [2003] and Turney [2008]) can be incorporated into our method. For instance, we could use *n*-gram patterns such as "either X or Y" and "from X to Y" to identify pairs of opposites that can be used as additional seeds in our method.

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Recall can also be improved by using affix patterns in other languages to identify contrasting thesaurus paragraphs in the target language. Thus, constructing a cross-lingual framework in which words from one language will be connected to thesaurus categories in another language will be useful not only in computing lexical contrast in a resource-poor language, but also in using affix information from different languages to improve results in the target, possibly even resource-rich, language.

8. Conclusions and Future Work

Detecting semantically contrasting word pairs has many applications in natural language processing. In this article, we proposed a method for computing lexical contrast that is based on the hypothesis that if a pair of words, *A* and *B*, are contrasting, then there is a pair of opposites, *C* and *D*, such that *A* and *C* are strongly related and *B* and *D* are strongly related—the contrast hypothesis. We used pointwise mutual information to determine the degree of contrast between two contrasting words. The method outperformed others on the task of solving a large set of "choose the most contrasting word" questions wherein the system not only identified whether two words are contrasting but also distinguished between pairs of contrasting words with differing degrees of contrast. We further determined performance of the method on five different kinds of opposites and across four parts of speech. We used our approach to solve synonym-or-opposite questions described in Turney (2008) and Lin et al. (2003).

Because opposites were central to our methodology, we designed a questionnaire to better understand different kinds of opposites, which we crowdsourced with Amazon Mechanical Turk. We devoted extra effort to making sure the questions are phrased in a simple, yet clear manner. Additionally, a quality control method was developed, using a word-choice question, to automatically identify and discard dubious and outlier annotations. From these data, we created a data set of different kinds of opposites that

Table 17
Results for individual components as well as certain combinations of components on the synonym-or-opposite questions in TURN. The best performing configuration is shown in bold.

	P	R	F
Baselines:			
a. random baseline	0.50	0.50	0.50
b. supervised most-frequent baseline†	0.65	0.65	0.65
Our methods:			
a. affix-generated seeds only	0.92	0.54	0.68
b. WordNet seeds only	0.93	0.61	0.74
c. both seed sets (a + b)	0.93	0.61	0.74
d. adjacency heuristic only	0.94	0.60	0.74
e. manual annotation of adjacent categories	0.96	0.60	0.74
f. affix seed set and adjacency heuristic (a + d)	0.95	0.67	0.78
g. both seed sets and adjacency heuristic (a + b + d)	0.95	0.68	0.79
h. affix seeds and annotation of adjacent categories (a + e)	0.97	0.68	0.80
i. **both seed sets and annotation of adjacent categories (a + b + e)**	**0.97**	**0.69**	**0.81**

†About 65.4% of the pairs in this data set are opposites. So this row reports baseline results when choosing opposites as the predominant class.

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Table 18
A summary of the data created as part of this research on lexical contrast. Available for download at: `http://www.purl.org/net/saif.mohammad/research`.

Name	# of items
Affix patterns that tend to generate opposites	15 rules
Contrast questions:	
GRE preparatory questions:	
Development set	162 questions
Test set	790 questions
Newly created questions:	1,269 questions
Data from work on types of opposites:	
Crowdsourced questionnaires	4 sets (one for every pos)
Responses to questionnaires	12,448 assignments (in four files)
Lexicon of opposites generated by the Mohammad et al. method:	
Class I opposites	3.5 million word pairs
Class II opposites	2.5 million word pairs
Manually identified contrasting categories in the Macquarie Thesaurus	209 category pairs
Word-pairs used in Section 5 experiments:	
WordNet opposites set	1,358 word pairs
WordNet random word pairs set	1,358 word pairs
WordNet synonyms set	1,358 word pairs

we have made available. We determined the amount of agreement among humans in identifying lexical contrast, and also in identifying different kinds of opposites. We also showed that a large number of opposing word pairs have properties pertaining to more than one kind. Table 18 summarizes the data created as part of this research on lexical contrast, all of which is available for download.

New questions that target other types of lexical contrast not addressed in this paper may be added in the future. It may be desirable to break a complex question into two or more simpler questions. For example, if a word pair is considered to be a certain kind of opposite when it has both properties M and N, then it is best to have two separate questions asking whether the word pair has properties M and N, respectively. The crowdsourcing study can be replicated for other languages by asking the same questions in the target language for words in the target language. Note, however, that as of February 2012, most of the Mechanical Turk participants are native speakers of English, certain Indian languages, and some European languages.

Our future goals include porting this approach to a cross-lingual framework to determine lexical contrast in a resource-poor language by using a bilingual lexicon to connect the words in that language with words in another resource-rich language. We can then use the structure of the thesaurus from the resource-rich language as described in this article to detect contrasting categories of terms. This is similar to the approach described by Mohammad et al. (2007), who compute semantic distance in a resource-poor language by using a bilingual lexicon and a sense disambiguation algorithm to connect text in the resource-poor language with a thesaurus in a different language. This enables automatic discovery of lexical contrast in a language even if it does not have a *Roget*-like thesaurus. The cross-lingual method still requires a bilingual lexicon to map words between the target language and the language with the thesaurus, however.

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Our method used only one *Roget*-like published thesaurus, but even more gains may be obtained by combining many dictionaries and thesauri using methods proposed by Ploux and Victorri (1998) and others.

We modified our algorithm to create lexicons of words associated with positive and negative sentiment (Mohammad, Dunne, and Dorr 2009). We also used the lexical contrast algorithm in some preliminary experiments to identify contrast between sentences and use that information to improve cohesion in automatic summarization (Mohammad et al. 2008). Since its release, the lexicon of contrasting word pairs was used to improve textual paraphrasing and in turn help improve machine translation (Marton, El Kholy, and Habash 2011). We are interested in using contrasting word pairs as seeds to identify phrases that convey contrasting meaning. These will be especially helpful in machine translation where current systems have difficulty separating translation hypotheses that convey the same meaning as the source sentences, and those that do not.

Given a particular word, our method computes a single score as the degree of contrast with another. A word may be more or less contrasting with another word when used in different contexts (Murphy 2003), however. Just as in the lexical substitution task (McCarthy and Navigli 2009), where a system has to find the word that can best replace a target word in context to preserve meaning, one can imagine a lexical substitution task to generate contradictions where the objective is to replace a given target word with one that is contrasting so as to generate a contradiction. Our future work includes developing a context-sensitive measure of lexical contrast that can be used for exactly such a task.

There is considerable evidence that children are aware of lexical contrast at a very early age (Murphy and Jones 2008). They rely on it to better understand various concepts and in order to communicate effectively. Thus we believe that computer algorithms that deal with language can also obtain significant gains through the ability to detect contrast and the ability to distinguish between differing degrees of contrast.

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