Self reference in word definitions

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Abstract – Dictionaries are inherently circular in nature. A given word is linked to a set of alternative words (the definition) which in turn point to further descendants. Iterating through definitions in this way, one typically finds that definitions loop back upon themselves. The graph formed by such definitional relations is our object of study. By eliminating those links which are not in loops, we arrive at a core subgraph of highly connected nodes. We observe that definitional loops are conveniently classified by length, with longer loops usually emerging from semantic misinterpretation. By breaking the long loops in the graph of the dictionary, we arrive at a set of disconnected clusters. We find that the words in these clusters constitute semantic units, and moreover tend to have been introduced into the English language at similar times, suggesting a possible mechanism for language evolution.

Introduction. – Words are the building blocks of language. By stringing together chains of these simple blocks, complex thoughts and ideas can be conveyed. For a language to be effective, this transmission must not only be precise but also efficient. Indeed, the continuous expansion of human languages tends to be driven less out of a need to express concepts that were previously uncommunicable, than by the constraint that concepts be transmitted rapidly. As a result of this need for efficient communication, the human lexicon is not a simple 1 to 1 mapping of concepts onto words, but rather a complex web of semantically related parts.

Network based formulations of human language have been employed previously to study language evolution. In this approach, words are considered to be the nodes of a graph with edges drawn based on a variety of possible relationships such as word co-occurrence in texts, thesauri, or word association experiments on human users [1, 2]. Such language networks tend to be scale-free and exhibit the small-world effect (*i.e.*, nodes are separated from one another by a relatively small number of edges), characteristics shared by many other complex, empirically observed networks [2].

The notion of a dictionary based graph, in which directed links are drawn between a word and the words in its definition, was proposed early on in view of using computational tools [3]. Dictionaries provide an important tool for studying the relationship between words and concepts by linking a given word to a set of alternative words (the definition) which can express the same meaning. Of course, the given definition is not unique. One might just as well replace all of the words in the definition of the original word in question, with their respective definitions. In the graph of the dictionary then, a word and its set of descendants can be viewed as semantically equivalent.

Recently, the overall structure of this dictionary graph was analyzed [4]. It was found that dictionaries consist of a set of words, roughly 10% the size of the original dictionary, from which all other words can be defined. This subgraph was observed to be highly interconnected, with a central strongly connected component dubbed the core. The authors then studied the connection of this finding with the acquisition of language in children.

The existence of the core reflects an important property of the dictionary, namely its requirement that every word have a definition (*i.e.*, a non-zero out-degree). The absence of "axiomatic" words whose definition is assumed results in a graph with a large number of loops, which is inherently not tree-like in structure. Here we study these definitional loops and show that they arise not as simple artifacts of the dictionary's construction, but rather as a manifestation of how coherent concepts are formed in a language. The distribution of loops in the actual dictionary differs markedly from the predictions of random graph theory. While the strong interconnectivity within the core normally obscures semantic relationships among its elements, by disconnecting the large loops of the graph, we are able to decompose the core into semantically related components. We show that by careful analysis of the interactions among these components, some of the central concepts upon which vocabulary is structured can be revealed. Finally, using additional etymological data, we demonstrate that words within the same loop tend to have been introduced into the English language at similar times, suggesting a possible mechanism for language evolution.

Dictionary Construction. – In order to construct an iterable dictionary, one must both reduce inflected words to their stems and resolve polysemous words to their proper sense. We therefore used as our primary dictionary eXtended WordNet, which provides semantically parsed definitions for each WordNet 2.0 synset (set of synonymous words) [5, 6]. To reduce complexity, we chose to restrict our attention to nouns as they are the part of speech generally most directly related to the main concepts within a text [7].

We treat the dictionary as a directed graph in which WordNet synsets are designated as nodes, with a directed link drawn from a node to all of the synset nodes which appear in its definition. With this construction each sense of a word is represented by a separate node. The resulting graph consists of 79,689 nodes and 285,773 edges. Its in-degree distribution obeys an approximate power law, while the out-degree is distributed randomly following a Poisson distribution. The in-degree and out-degree distributions we observed are consistent with those found in [4].

For our studies, we found it convenient to represent this graph as an adjacency matrix. The process of iterating through definitions then corresponds to taking successive powers of the adjacency matrix, with loops appearing as non-zero entries in the diagonal.

The Core. – The current lexicon arose out of the need to express concepts both precisely and concisely. As such, there should exist not only words that expand the breadth of ideas we are able to communicate, but also those that simply serve to increase the efficiency of information transfer. To isolate those words which form the *conceptual* basis of the English language, we calculate the "descendants" of each word in the dictionary, namely all nodes which can ultimately be reached along a directed path from the given starting point. Surprisingly, as illustrated in fig. 1, we find that these sets of descendants are almost completely independent of the starting point used to reach them, intersecting in a 6,310 node set which we label as our core[1].

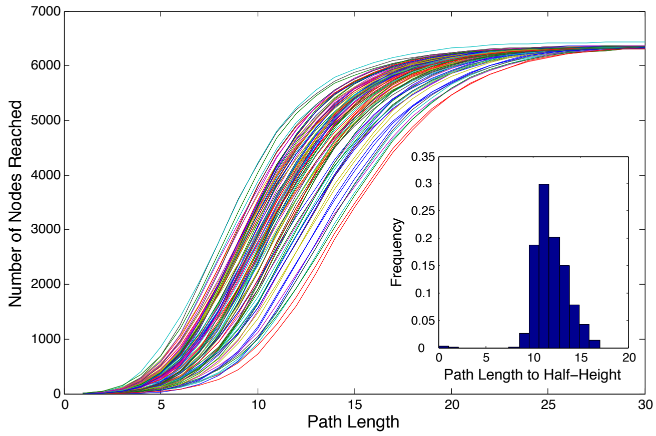


Fig. 1: Definitional iteration of words in the dictionary. Using a random sample of 100 words, the number of unique nodes that could be reached within the given distance of each node was recorded. Nearly all words ultimately reach a common set of 6,310 words which we call the core of the dictionary. The convergence to the core is both rapid, as seen in the distribution of path lengths to half height (inset), and complete, indicating a very high concentration of loops within the core. Note that several words in our sample were not connected to the core, existing instead as part of small isolated definitional loops. The half-height in these samples is therefore reached almost immediately.

While the existence of a central strongly connected has been demonstrated in similar dictionary graphs previously [4], the speed at which the definitional paths converge on the core is surprising (inset to fig. 1). After only twelve steps most paths will have already encompassed half the core, and by thirty, all descendants will have already been reached. This behavior suggests that the core contains a very high concentration of overlapping loops because, otherwise, if there were disjoint sinks, the algorithm would lead to one of them and miss the full height.

Our set of core words should theoretically be sufficient to define all words in the dictionary, albeit with extensive paraphrasing, and thus can be thought of as a simple vocabulary. Having constructed this dictionary core by purely computational means, it is interesting to compare the words in it to other simple lexicons. We compared our core to Basic English [8], a set of 850 words British linguist Charles Ogden claimed sufficient for daily discourse, as well as to the English translations of the words in Jōyō Kanji, the Japanese Education Ministry's list of 1,945 characters required to be learned by Japanese secondary school students (accessed from [9]). As a control, we also

[1]To ensure that this result was not an anomaly of WordNet glosses, we constructed a graph using the English Wiktionary [11] by associating each word with the first sense of its definition. Although this set is a mere crude construction, a core of $\sim 2,500$ words (out of $\sim 80,000$) emerged in an identical fashion.

	Core	Basic English	Jōyō Kanji	Gutenberg
Core	1595	314 (52%)	403 (29%)	265 (39%)
Basic English		600	328 (24%)	213 (32%)
Jōyō Kanji			1376	319 (47%)
Gutenberg				673

Table 1: Intersection of core with other simple word lists. Table entries represent the number of words in the intersection of the sets, with percent overlap given in parentheses. The core was reached using a simplified WordNet dictionary graph, in which nodes were words (not synsets) with only the first sense of the definition considered. Only nouns in each word list were considered. Descriptions of the word lists are found in the main text.

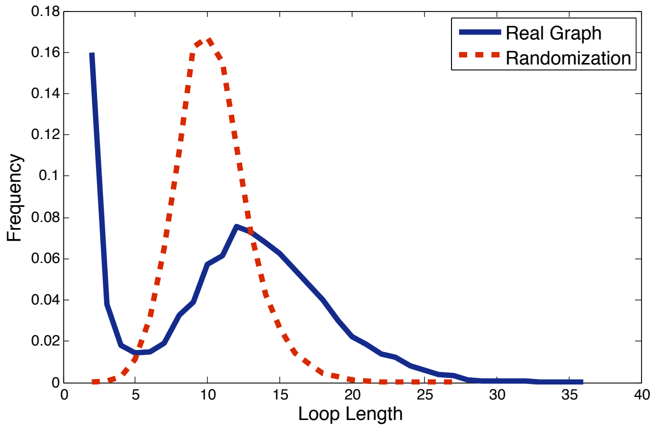


Fig. 2: Distribution of definitional loops in the dictionary. The data represent counts of links in the core indexed by the shortest loop in which they appear. For the randomization, links were randomly redrawn between nodes while keeping the in-degree and out-degree distributions of the graph constant.

compared these lists to the top 1000 most frequently used words in all books found on Project Gutenberg (accessed from [10]). As these lists were of course not sense disambiguated, we temporarily reduced the resolution of our graph by making the nodes words (instead of synsets) and using only the first sense of the definition. Again, only nouns were considered in all comparisons.

Our new set of 1595 core words did share great overlap with all three lists (see Table 1). Notably, however the overlap never exceeded 50% of any word list. A survey of the words in Basic English not found in the core reveals a trend of potentially useful but perhaps definitionally "over-specific" words such as *apple, brick, chalk, hammer*, and *glove*. While these words might come in handy in daily life, as Ogden had intended, it is easy to see how these words would be reduced in our dictionary into more general words which in combination can communicate these more specific words (*e.g.*, in the case of *apple*, both *fruit* and *red* appear in our core).

The Decomposition. – The manner in which we were able to reach the core suggests the somewhat counterintuitive idea that all words are conceptually interconnected. In order to better characterize the connections which lead to the emergence of our core, we searched for definitional loops within the dictionary. We found that a total of 9,085 nodes in our graph were elements of loops. The core itself was saturated with loops with over 99% of its elements being involved in cycles within it.

The distribution of loop lengths, shown in fig. 2, in the dictionary is illuminating. It appears that cycles in the dictionary fall into two classes: short (≤ 5) and long (> 5). While the appearance of long loops can be predicted solely based on the in and out degree distributions of our graph (the randomization in the figure), the short loops appear to be a unique feature arising from *meaningful* connections between nodes. Inspection of individual loops confirms this assessment, with small cycles following a very clear conceptual path while large cycles are for the most part characterized by one or more conceptual leaps, typically caused by a misinterpretation of word sense as the following example illustrates.

$$\textit{railcar} \to \textit{rails} \to \textit{bar} \to \textit{weapon} \to \textit{instrument} \to \textit{skill} \not\to \textit{train} \to \textit{railcar}$$

Though the link between bar and weapon is perhaps questionable, the link between skill and train clearly is a case of mistaken sense, in this case between "train" the verb and "train" the noun. Such errors reflect the fact that the semantic tagging in eXtended WordNet was done largely computationally and is therefore subject to mistakes. We have observed, however, that the ratio of large to small loops is considerably lowered when links are assigned based on the semantic tag in eXtended WordNet instead of being assigned using naïve, usage frequency based approaches (data not shown).

Fig. 2 also shows a slight overabundance of links involved in large loops in the dictionary as compared to the randomization. This longer tail appears to result from the fact that not all connections within a long loop are false as illustrated in the example loop above. It therefore takes more connections for a false loop to form in the real data than in the randomization where *every* link is likely wrong.

The finding that long loops generally emerge as a result of semantic misinterpretations, suggests that the core is in fact structured among sets of small, albeit interrelated, loops. Indeed, when we considered only the links in the core involved in small loops, we found that the core decomposed into several hundred isolated, strongly connected components which show thematic convergence (Table 2). The size of these components ranged from 2 to 94. For subsequent analysis we further resolved components with size greater than twenty by considering only the links involved in four loops within them, yielding a total of 386 components.

It is important to note that given the high-degree of connectivity between loops, large loops did exist within some

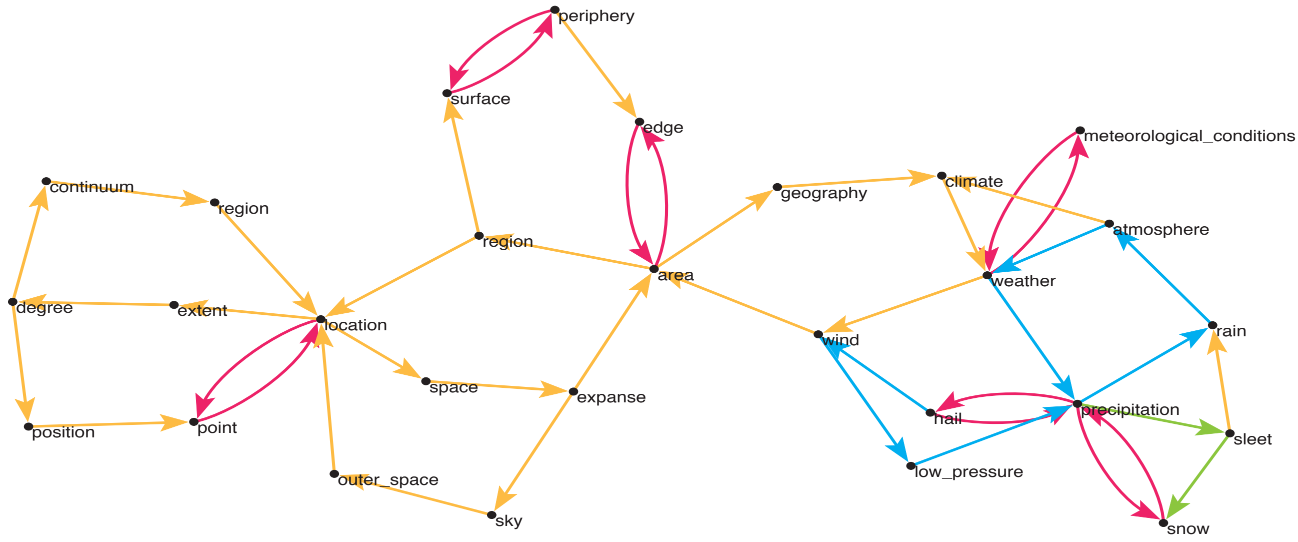


Fig. 3: An example of a large connected component in the decomposition. Arrows are drawn from a node to words in it's definition. Red links appear first in two loops, green in three loops, blue in four loops, and orange in five loops.

emotion spirit dejection melancholy feeling	height end dimension length	bark trunk tree lumber	injury violence accident	winner contestant competition

Table 2: Examples of strongly connected components in the decomposed core.

of these components. The links within these large loops, however, were simultaneously involved in small loops and as a result generally followed a logical progression of ideas. Fig. 3 provides a graphical view of one of the larger components in our decomposition, emphasizing the embedding of small loops within the overall component.

Though clusters in our decomposition are built upon distinct semantic ideas, they are *not* conceptually orthogonal to one another since different loops actually share edges. Meaningful connections between the connected components do of course exist, our results suggesting simply that these connections are generally acyclic in nature (*i.e.*, loops can be found only within clusters, not between them). In order to better characterize the interactions among components and their role in the overall dictionary, we wish to "define" each word in the dictionary in terms of the semantic clusters. To quantify the importance of each component in the definition we count the number of paths in our original graph leading from the word to a given cluster. In an attempt to increase the definitional weight of clusters located close to the word in question, we allowed vertices and edges to be repeated when counting paths so that the number of paths to a closer cluster continues to grow in the time taken to reach a farther one. This choice requires us to impose a bound on the length of path we consider. We choose this upper limit in path length as 5, in keeping with our finding that loops of size greater than 5 usually emerge from semantic misinterpretations. Each node in the original graph can now be associated with a vector whose elements are the number of paths from that node to each of the 386 components. Concatenating these vectors yields a sparse $79,689 \times 386$ matrix.

In analyzing this matrix we found that five components appeared in over 80% of the vectors. Not surprisingly these components consisted of very general words (*e.g.*, "entity" and "group") and were thus ignored in further analysis and removed from the matrix. In an attempt to identify cohesive groups of connected components, we performed singular value decomposition (SVD) on our matrix. The resulting singular vectors (examples of which can be found in Table 3) show a striking ability to capture major themes within the dictionary including geography, life, and religion. It is however the connections between the elements in these singular vectors that are most significant. Though normally obscured by noisy connections in the dictionary, links among topics such as the body, water, energy, and disease in our singular vectors reflect powerful semantic chains underlying the *conceptual* lexicon.

Loop Etymology. – As we have seen, definitional loops underlie much of the core structure of the dictionary. When one considers the evolution of a language, the question arises how such loops in meaning came to exist. Using the Online Etymology Dictionary [12], we manually looked up the dates of origin for words in small loops (namely the connected components in our decomposition). Dates were recorded only when the definition given in the dictionary matched the sense of the word in

Vector 1	Vector 2	Vector 5	Vector 6	Vector 8
Old World, oceans	*spine, brain*	grains	*body parts*	Jesus, Christianity
bodies of water	*body parts*	*bodies of water*	*flower, seed*	man, woman
The Americas	Old World, oceans	herbage	*tree, bark*	*nucleus, DNA*
influence, power	*energy*	flower, seed	grains	Roman Empire
	pathology	*land*	nucleus, DNA	student, teacher
	narrative	*water*	spine, brain	speaker, speech
	cognition		*Gymnosperms*	Vatican, absolution
	organic process		bodies of water	Old Testament
	respiration		pathology	book

Table 3: Examples of the highest singular components for the dictionary. The elements in the singular components are the semantically cohesive clusters of words obtained from decomposing the core. For table entries, word(s) representing the main theme of each cluster were chosen. Clusters are listed in order of the absolute value of their coefficient in the singular component. Only components whose absolute values were greater than 0.1 were listed. Plain text and italics indicate positive and negative values respectively. The 3rd, 4th, and 7th highest singular components were very similar to the vectors shown and therefore not displayed.

the loop and in the case of synsets with multiple words, only the first word in the synset was used. Given the considerable vagueness surrounding dates of emergence in Old English, for the purposes of our analysis all Old English words were recorded as having emerged in the year 1150.

After eliminating proper nouns and compound words, we found dates for 971 words distributed among 310 connected components. As shown in fig. 4a, the distance among dates of origin of words in the components is for the most part considerably smaller than that obtained by randomly clustering these dates. While several components do contain words with somewhat disparate dates of origin, we found that such exceptions often reflected fundamental changes in the understanding of a word after its introduction. For instance, the word “cell” was in use several hundred years before the discovery of DNA, but since that event the two ideas have become conceptually interdependent. Interestingly, the distribution of mean dates of origin for each component (fig. 4b) is bimodal in nature. This distribution is perhaps indicative of major periods of *conceptual* expansion within the English language, with most growth appearing to occur between the 14th-16th centuries, with a secondary growth of largely scientific words emerging in the last two centuries.

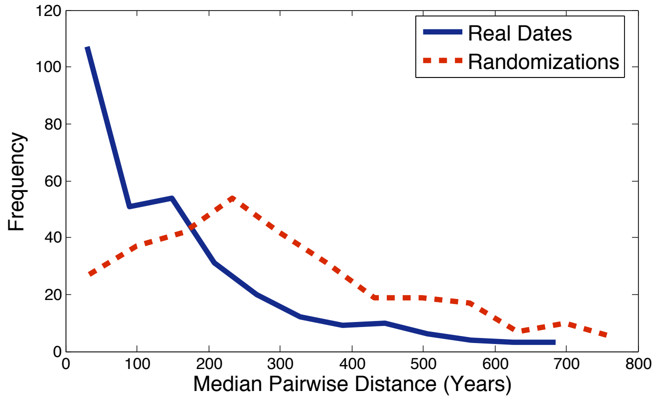
The apparent coevolution of words in loops is quite striking. While words in a loop are of course semantically related, there is no a priori reason to assume that semantically related words in general emerge around the same time period. For instance, the word “sneaker” is clearly closely related to the word “shoe”, yet it is not surprising that the two words emerged at very different epochs (the Online Etymology Dictionary places sneaker in 1895 and shoe in Old English). The finding that words in loops are typically introduced into language at the same time thus appears to reflect the unique type of semantic relationship they share.

Conclusions. – Dictionaries possess widespread circularity in definitions. We have shown that the loop structure of actual dictionaries varies dramatically from that which would be predicted based on random graph theory alone. Specifically, we found that dictionaries rely on short loops of between two to five words in order to define co-dependent concepts. While long range loops do exist, they often arise as a result of semantic misinterpretation. Indeed, it appears to be these false loops which account for the strongly connected nature of the dictionary core, obscuring pockets of meaning within it.

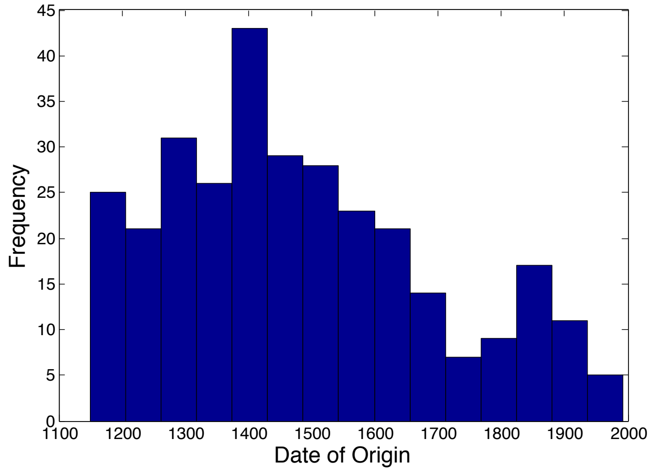
In order to isolate “true” loops within the dictionary, we disconnected all links between nodes which do not appear in loops of size five or smaller. Due to strong interconnectivity among certain loops, this approach importantly did not lead to the dissolution of all long loops. Rather, our graph decomposed into a number of strongly connected components formed by collections of overlapping, short-ranged loops which show thematic convergence.

Our finding that the words within a loop (*i.e.*, elements of the same strongly connected component in our decomposition) were generally introduced into the English language in the same time period underscores the unique relationship among words involved in a definitional loop. Although in theory one need only know the meanings of some subset of the words in a loop in order to infer the definitions of the remaining words, at the conceptual level the meanings of these words remain completely intertwined.

This of course begs the question of how loops could have come to exist in the first place. In order for a word to be introduced into language it must be understood by multiple individuals to mean the same thing. The necessary synchronization of word meaning among different individuals is particularly difficult when the meanings themselves exist as conceptual loops. A potential solution to this problem is for an individual to attempt to sequentially define all the elements of the loop. While the central concept



(a)



(b)

Fig. 4: Dates of origin of words in loops. For each component in the decomposition, the dates of origin of its element words (in the desired sense) were looked up in the Etymology Dictionary. Compound words and proper nouns were ignored, as well as polysemous words. The median pairwise distance of elements (a) and the mean date of origin (b) were calculated for each of the 310 components in our analysis.

of the loop cannot be directly communicated, we propose that the juxtaposition of the partially defined elements within the loop allows the receiver to infer the common link among the words, thereby completing the definition of all words in the loop. Such a system is consistent with our finding that words within a loop tend to enter the lexicon at the same time and, if correct, suggests that definitional loops are not simply a mathematical artifact of dictionaries, but rather a key mechanism underlying language evolution.

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