

The semantic drift of quotations in blogspace: a case study in short-term cultural evolution

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We describe reformulation processes within a large distributed system such as blogspace; showing how some specific features of public representations may be altered by bloggers when they freely reproduce them. To deal with robust and simple cultural representations, we focus on the evolution of quotations. In particular, we uncover some of the semantic and structural characteristics of individual words and the substitutions they undergo. Our work amounts to a large *in vivo* experiment where we appraise the impact of classically-influent psycholinguistic variables in the accuracy of the reproduction. We show that all variables remarkably exhibit a single attractor and are generally contractile. Even though the observed convergence patterns only partially explain quotation evolution, we shed light on a class of phenomena which are prone to constitute a key element of a broader empirically-grounded, attractor-based theory of cultural evolution. [Update after introduction rework.](#)

Keywords: word production; recollection bias; semantic network; cultural evolution; cultural attraction; data mining; big data; *in vivo* psycholinguistics

Introduction

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TOO GENERAL OR GIVES THE IMPRESSION OF TOO HIGH AMBITIONS. COMPARE TO OTHER INTROS TO JUST SAY WE'LL TALK ABOUT THIS.

Since the very beginnings of both social science and psychology, scientists have tried to capture the way cognition and culture influence each other. While this has been the subject of intense debate in the social sciences in the 20th century (starting with Durkheim's initial works, 1912, later tackled in earnest by e.g. Mauss' *Techniques of the Body*, 1936, Giddens' *Structuration Theory*, 1984, and Bourdieu's *Sens Pratique*, 1980), today's discussion is mostly structured by proponents from cognitive science.

These construe culture as an evolutionary process analogous and parallel to biological evolution (and especially the modern synthesis' account of it). That analogy can be traced a long way back in the 20th century and earlier, with milestones such as Kroeber's works (1952), Dawkins' *Memet-*

ics (2006), and later the development of *Dual Inheritance Theory* by Boyd and Richerson (1985) and Cavalli-Sforza and Feldman (1981) among others. More recently, Dan Sperber has drawn on this principle to explicitly connect anthropology and cognitive science through the theory of *Epidemiology of Representations* (Sperber, 1996), and the study of cultural evolution has been growing steadily since.

The collection of works by Aunger (2000) (in particular Bloch, 2000, and Kuper, 2000) has shown how the theory of memetics cannot account for the levels of transformation culture undergoes as it is transmitted. Mesoudi and Whiten (2008) have discussed the uses of transmission chain experiments to test what dual inheritance theory can explain about cultural evolution. Morin (2013) and Miton, Claidière, and Mercier (2015), by carefully compiling a series of anthropological works, show how cognitive biases have influenced the evolution of cultural artifacts over several centuries. Kirby, Cornish, and Smith (2013; 2008) have shown how evolutionary pressures lead to the emergence of structured and expressive artificial languages in simulations and laboratory experiments. Such transmission chain experiments have also been explored in non-human primates by Claidière, Smith, Kirby, and Fagot (2014).

The theory of epidemiology of representations proposes a unifying framework for all these works by recasting them

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as questions of spread and transformation of representations: these are alternatively located in the mind ("mental representations" in Sperber's terminology), or in the outer world ("public representations") as expressions of mental representations in diverse cultural artifacts (pieces of text, utterances, pictures, building techniques, etc.). A human society is then modeled as a large dynamical system of people constantly interpreting public representations into mental representations, and producing new public representations based on what they have previously interpreted. Two key points are that (a) transmission is not reliable (representations change significantly each time they are interpreted and produced anew, as opposed to e.g. memetics), and (b) the reciprocal influences of cognition and culture can be captured by studying the evolution of public representations themselves, which is what the studies cited above are doing.

The theory makes an additional strong hypothesis, which this paper focuses on: as transformations accumulate, some representations evolve to be very stable and spread throughout an entire society without changing any more (they are called "cultural representations", because they characterize a given culture). This process should manifest itself as attractors (called "cultural attractors") in the dynamical system that models cultural evolution, that is: there should be areas of the representation space where cognitive effects in transformations bring representation closer to a given stable asymptotic point.¹

This hypothesis, a cornerstone of the theory because of the intelligibility it gives to cultural evolution, has been hard to test in concrete situations as quantitative data on out-of-laboratory cultural artifacts is not easy to collect. One approach, as mentioned above, has been the meta-analysis of large bodies of anthropological studies (see Miton et al., 2015, for instance). This paper exemplifies a second approach, taking advantage of the ever-increasing avalanche of available digital footprints since the 2000's. Indeed, tools and computing power to analyze such data are now widespread, and the body of research aimed at describing online communities and content is growing accordingly. For instance, the propagation of cultural artifacts across social networks has been studied in blogspace (Gruhl, Guha, Liben-Nowell, & Tomkins, 2004) and in the email network (Liben-Nowell & Kleinberg, 2008); Cointet and Roth (2009) have described the reciprocal influence between the social network topology and the distribution of issues; Leskovec, Backstrom, and Kleinberg (2009b) detailed the characteristic times and diffusion cycles both within these social networks and with respect to the topical dynamics of news media, and Danescu-Niculescu-Mizil, Cheng, Kleinberg, and Lee (2012) have studied the characteristics of particularly memorable quotes that circulate in those networks. We believe those works can connect the field of cultural evolution with psycholinguistics to advance the testing of cultural attractors.

add examples

To show this we analyze the way quotes in blogs and media outlets are modified when they are copied from website to website. These public representations should normally not change as they spread on the Web (as opposed to more elaborate expressions or opinions, not identified as quoted utterances), but empirical observation shows that they are in fact occasionally transformed (Simmons, Adamic, & Adar, 2011): authors spontaneously transform quotes, not only cropping them but also replacing words, when in fact they are implicitly required to copy them exactly. We can therefore assume that most transformations, especially the simple ones, are the result of automatic (i.e. hard to control) low-level cognitive biases of the authors.

Our question is as follows: given such representations that seem to evolve precisely because of the kind of automatic cognitive biases referred to in the theory of epidemiology of representations, do cultural attractors appear and how do cognitive biases participate in them? We chose to restrict our analysis to substitutions (one word being replaced by another), both to keep the analysis tractable and because of missing information in our data set.² While this restricts the scope of our observations for the particular data set we use, the methodological point we also make is left intact. By characterizing words with 6 well-known features, we identify what makes a substitution more likely, and how a word changes when it is substituted. This exploratory approach uncovers a number of transmission biases consistent with known effects in linguistics. While the transformations we describe are not the only ones at work in this data set, our analysis also indicates that feature-specific attractors could exist because of the substitution process. This study can be viewed as analyzing part of the transmission step operating in transmission chains of artificial languages like those studied by Kirby et al. (2008), but with natural language out of the laboratory.

The next section describes our hypotheses along with a review of the psycholinguistics literature. Then, we describe the data set and detail the various assumptions that were made in order to analyze it. Next, we describe the measures built to observe the cognitive biases operating in quote transmission. Finally, we discuss the relevance of these results for the study of cultural evolution, followed with general guidelines for further work.

¹Attractors need not be points in fact, they can also be sub-areas; in that case any transformation brings representations in the area closer to (or maintained inside) the target sub-area.

²As explained further down, source-destination links between quotes must be inferred from the data set, an operation which is much more reliable if we restrict our analysis to substitutions. This also impedes us from observing the effect of accumulated transformations in the long term, limiting our results to a view of the individual evolutionary step.

Related work

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The study of cultural evolution on the part of cognitive science emerged only recently. While formal models of cultural transmission appeared with the development of dual inheritance theory (Boyd & Richerson, 1985; Cavalli-Sforza & Feldman, 1981) and have included the notion of cultural attractor since then (Claidière, Scott-Phillips, & Sperber, 2014; Claidière & Sperber, 2007), collecting data to test and iterate over such models has been more challenging. The first method mentioned above consists in rebuilding the history of a given type of representation by compiling anthropological or historical works on the subject (as for instance Morin, 2013, and Miton et al., 2015, have done).³ A second approach uses cultural evolution experiments in the laboratory, with an array of methods reviewed by Mesoudi and Whiten (2008). Transmission chains, in particular, have been used extensively to study the evolution of human language (see Tamariz & Kirby, 2016, for a review). Other recent examples include studies of the evolution of simple audio loops through consumer preference (MacCallum, Mauch, Burt, & Leroi, 2012), the emergence of structure in visual patterns transmitted by baboons (Claidière, Smith, et al., 2014), and the amplification of risk perception through chains of casual conversation (Moussaïd, Brighton, & Gaissmaier, 2015).

Research on online content points to a third approach to this question. By investigating the transformations of quotations in a large corpus of US blog posts and online news stories initially collected and studied by Leskovec et al. (2009b), Simmons et al. (2011) and later Omodei, Poibeau, and Cointet (2012) show that even for quotations, a type of public representation that should change the least when transmitted on the Web, it is still possible to witness significant transformations. These studies focus on the influence of the quotation source (e.g. news outlet vs. blog) or of the surrounding public space (e.g. quotation frequency in the corpus), and suggest diffusion-transformation models to capture the dynamics of the population of quotations. But the cognitive features which may determine or, at least, influence these transformations, are overlooked. Yet cognitive and linguistic features have been used in studies not involving transformation: Danescu-Niculescu-Mizil et al. (2012), for instance, show that particularly memorable quotations (taken from movie scripts in this case) use more distinctive words and have more common syntax than less memorable quotations; they are also the quotes that adapt best to new contexts of use. One source of ideas to study the transformations of such quotes, then, might be the psycholinguistic literature studying word and sentence recall.

Potter and Lombardi (1990) suggest that immediate recall of sentences is based on the retention of an unordered list of words which is then regenerated as a sentence at the moment

of production. Priming recall with other words can lead to replacement in the recalled sentence if the primed words support the overall meaning of the sentence. Regenerated syntax can also be influenced by priming recall with another syntactic structure (Potter & Lombardi, 1998), or with verbs whose category constraints call for a different structure (Lombardi & Potter, 1992).

Compared to full sentences, recall of word lists provides a situation that is easier to fully explore, and that has been extensively studied. In particular, the Deese, Roediger, and McDermott paradigm (introduced by Deese, 1959, and later popularized by Roediger & McDermott, 1995) has shown that it is possible to construct lists of words which reliably create the false memory of an external word related to those in the list. This is done by using lists of words produced by free association from the target intrusion word; the intruding recall then happens with probability nearly proportional to the average strength of semantic association between the intruding word and the words in the list. A sizable literature studies this type of task with varying complexities in the design of the lists, a good review of which is given by Zaromb et al. (2006). One notable effect is that the semantic relations between words greatly influence, and correlate to, the order in which words are recalled (Howard & Kahana, 2002; Tulving, 1962), and that this reordering of items improves subjects' repeated recalls (Tulving, 1966). The frequency and type of intrusions in lists of random words are also influenced by associations created by the presentation of previous lists (Zaromb et al., 2006); indeed the question of how such temporal associations (contributing to contextual information retrieval in recall) interact with the prior semantic associations of subjects (contributing to associative information retrieval) is at the center of many of these studies.

These effects don't transpose simply to sentence recall however, as not only syntax but also effects of attention come into play for both retrieval and encoding. Jefferies, Lambon Ralph, and Baddeley (2004), for instance, show that attention is central to the encoding and retention of unrelated propositions, on top of more automatic syntactic and semantic processes. This involvement of executive resources also seems to contribute to the much greater memory span subjects exhibit for sentences compared to word lists (see Jefferies et al., 2004, again, for more details).

Given this complexity we decided to focus on more aggregate effects, where variations of the conditions in which sentences are read and produced have a chance of being statistically smoothed out.⁴ If a cognitive bias in the substitu-

³Critics like Ingold (2007), however, have noted that the quantitative use of data imported from the social sciences risks overlooking the ontological debates in history and anthropology over the way to interpret such data.

⁴Aside from our lack of control on the precise conditions of en-

tion of words manifests itself with simple measures, then it will be worth applying predictive models of the substitution process in further research.

Lexical features, then, are obvious well-studied word measures that can be analyzed in aggregate. Indeed word frequency (see Yonelinas, 2002, for a review), age-of-acquisition (Zevin & Seidenberg, 2002), number of phonemes (see for instance Nickels & Howard, 2004; Rey, Jacobs, Schmidt-Weigand, & Ziegler, 1998), and phonological neighborhood density (Garlock, Walley, & Metsala, 2001) to name a few, all have known effects on word recognition or production. More complex features based on word networks built from free association or phonological data have also been analyzed: Nelson, Kitto, Galea, McEvoy, and Bruza (2013) for instance, show the importance of clustering coefficient in such a semantic network by studying the role it plays in a variety of recall and recognition tasks (extralist and intralist cuing, single item recognition, and primed free association). Chan and Vitevitch (2010) show that pictures are named faster and with fewer mistakes when they have a lower clustering coefficient in an underlying phonological network. Griffiths, Steyvers, and Firl (2007) analyze a task where subjects are asked to name the first word which comes to their mind when they are presented with a random letter from the alphabet. The authors show that there is a link between the ease of recall of words and their authority position (pagerank) in a language-wide semantic network built from external word association data (Austerweil, Abbott, & Griffiths, 2012, further develop this tool to give a parsimonious account of the fact that related words are often retrieved together from memory).

On the whole, research on lexical features hints towards two antagonistic types of effects (also known as the "word-frequency paradox", Mandler, Goodman, & Wilkes-Gibbs, 1982). On one hand, part of the literature shows that recall is easier for the least "awkward" words; those whose age of acquisition is earlier, length is smaller, semantic network position is more central — this is particularly true in retrieval, that is in tasks where participants are asked to form spontaneous associations or utter a word in response to a given signal. On the other hand, when the task consists in recognizing a specific item in a list, "awkward" words are actually more easily remembered, possibly as they are more informative and plausibly more discernible (see again Yonelinas, 2002, for a review). The jury is still out as to whether reformulation alteration, that is spontaneous replacement of words when asked to rewrite a given utterance, is rather of the former or latter sort. We also aim to shed some light on this debate, considering oddness as a dimension of the purported fitness of utterances.

Methods

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Quotations appeared to be a perfect candidate to propose a first measure of [automatic](#) cognitive bias in [cultural transmission](#). First, they are usually cleanly delimited by quotation marks which greatly facilitates their detection in text corpora. Second, they stem from a unique original version, and are ideally traceable back to that version. Third, and most importantly, their duplication should *a priori* be highly faithful, apart from cases of cropping: not only should transformations be of moderate magnitude, but when specific words are not perfectly duplicated, it is safe to assume that the variation is due to involuntary cognitive bias — as writers may expect any casual reader to easily verify, and thus criticize, the fidelity to the original quotation.

We could therefore study the individual transformation process at work when authors alter quotations, by examining the modified words in each transformation. [Since our approach is exploratory](#) however, we do not know at the outset which precise effect of cognitive bias we are looking for. Indeed the data we use does not come from a controlled experiment in the laboratory, designed to elicit a particular effect: they are recordings of real life interactions, with all the complexity and uncertainty of conditions this entails. In this first study, therefore, we did not try to predict and explain in detail the cognitive processes responsible for transformations, as this would be akin to a drink from the firehose. Our goal, instead, is to show that such effects exist and are measurable, even if they are part of a larger complexity. That is, we aim to prove first a relatively weak hypothesis before trying stronger ones. If this is confirmed, we will have successfully applied laboratory analyses to out-of-laboratory data, opening a path to explanations of actual (vs. simulated) cultural evolution with tools from cognitive science. As explained in the previous section, this is the reason we chose to use measures that can aggregate over all the transformations in the data set.

To keep the analysis [tractable](#), we focused on quotation transformations consisting in the *substitution* of a word by another word (and only those cases) in order to unambiguously discuss single word replacements. [This restriction also allows us to more reliably infer the information that is missing in our data set, as explained further down \(see "Substitution model"\)](#). To quantify those substitutions we decided to associate a number of features to each word, the variation of which we can statistically study.

coding and recall in our data set, the analysis techniques mentioned above are better suited to data consisting of a high number of measures over a smaller number of lists (in which case it makes sense to ask e.g. what proportion of intrusions come from prior lists). As is explained further down however, our data set is shaped the opposite way: a great number of sentences, with only very few to no measures at all on each sentence.

The next subsections describe the data set and the measures we used to assess this cognitive bias.

In vivo utterances

We used a quotation data set collected by Leskovec et al. (2009b), large enough to lend itself to statistical analysis. This data set consists of the daily crawling of news stories and blog posts from around a million online sources, with an approximate publication rate of 900k texts per day, over a nine-month period of time from August 2008 to April 2009 (Leskovec, Backstrom, & Kleinberg, 2009a; unfortunately, the original article, Leskovec et al., 2009b, does not provide further details on the source selection methodology). The authors automatically extracted quotations from this corpus. Each quotation is a more or less faithful excerpt of an utterance (oral or written) by the quoted person; for instance:

The Bank of England said, "these operations are designed to address funding pressures over quarter-end."

Then, the authors gathered quotations in a graph and connected each pair that differed by no more than one word or that shared at least ten consecutive words (they tested this procedure with a number of different parameters, see Leskovec et al., 2009b, for more details). We find for example the following variation of the above quote:

"these operations are **intended** to address funding pressures over quarter-end."

Next, they applied a community detection algorithm to that quotation graph to detect aggregates of tightly connected, that is sufficiently similar, groups of quotations (see again Leskovec et al., 2009b, for more details). This analysis yielded the final data we had access to, with a total of about 70,000 sets of quotations; each of these sets ideally contains all variations of a same parent utterance, along with their respective publication URLs and timestamps (since the procedure cannot be perfect, sets of quotations contain occasional rogue unrelated variations that should have been discarded or assigned to another set).

Manual inspection of this data set revealed that it contains a significant number of everyday language quotations (such as "it was much better than I expected", "did that just happen", as well as many simple expletive-based sentences). Their presence is largely due to random variations around casual expressions, while we are interested in transformations of news-related quotes causally linked to an original, identifiable utterance. To filter them out, we exclude quotes with less than 5 words or whose occurrences span more than 80 days (indicating causally unrelated occurrences), as well as quotes not written in English. Clusters that are emptied by

this procedure are therefore excluded. If, after this screening, a cluster's occurrences still span more than 80 days (because of short-lived but unrelated quotes far apart in time), we also exclude it. We eventually keep 50,427 clusters (out of 71,568; i.e. 70.5%), containing a total of 141,324 unique quotes (out of 310,457; i.e. 45.5%) making up about 2.60m occurrences (out of 7.67m; i.e. 33.9%).⁵ Even if we lose some real event-related utterances which are present in clusters lasting more than 80 days (one such lost quote, for instance, is "the city is tired of me and the organization and I have run our course together"), we check that our approach fulfills its goals by coding a random sub-sample of 100 clusters: 35 of them are rejected by the filter, with 15 false negatives (rejected clusters that should have been kept) and 9 false positives (clusters kept when they should have been rejected), giving a precision score of 0.862 and a recall score of 0.789. Furthermore, all but one of the 9 false positives are left with a single non-rejected quote, meaning those clusters are ignored by our substitution analysis; this brings the effective precision of our filter to 0.982.⁶

Word-level measures

Lexical features. We first introduce some lexical measures on words.

- **Word frequency:** the frequency at which words appear in our data set, known to be relevant for both recognition and recall (Gregg, 1976),

- **Age of Acquisition:** the average age at which words are learned (obtained from Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012), known to have different effects than word frequency (Dewhurst, Hitch, & Barry, 1998; Morrison & Ellis, 1995),

- **Phonological and Orthographic Neighborhood Density** (obtained from Marian, Bartolotti, Chabal, & Shook, 2012), also known to be relevant for word production (Garlock et al., 2001),

- The average **Number of Phonemes** and **Number of Syllables** for all pronunciations of a word (obtained from the Carnegie Mellon University Pronouncing Dictionary, Weide, 1998)⁷, as well as **Number of Letters**, as a proxy to word production cost,

⁵The significantly larger loss in occurrences indicates that, on average, the clusters we lose contain more occurrences than those we keep, which is to be expected for everyday language utterances.

⁶A similar analysis was made for language detection, which is part of the cluster filtering: out of 100 randomly sampled quotes, 17 are rejected because their detected language is not English, with no false positives and 6 false negatives, giving a precision score of 1 and a recall score of 0.933. Of the 6 false negatives, 4 had less than 5 tokens and would have been excluded by the cluster filter anyway.

⁷The CMU Pronouncing Dictionary is included in the NTLK package (Bird, Klein, & Loper, 2009), the natural language processing toolkit we used for the analysis.

- The average **Number of Synonyms** for all meanings of a word (obtained from WordNet, 2010) as an *a priori* indicator of how easy it would be to replace a word.

We also consider grammatical types within quotations by detecting *Part-of-Speech* (POS) categories with TreeTagger (Schmid, 1994); we distinguish between verbs, nouns, adjectives, adverbs, and stopword-like words.

Aside from these raw features, the systemic dimension of vocabulary (Cornish et al., 2013) has led authors to develop measures based on the full topology of networks built from free association data or phonological similarity. Several such measures have been shown to be involved in recall, recognition, and naming tasks (Chan & Vitevitch, 2010; Griffiths et al., 2007; Nelson et al., 2013).

To compute those features we relied on the free association (FA) norms collected by Nelson, McEvoy, and Schreiber (2004), which record the words that come to mind when someone is presented with a given cue. As Nelson et al. (2004) explain, "free association response probabilities index the likelihood that one word can cue another word to come to mind with minimal contextual constraints in effect." Similar to what Griffiths et al. (2007) did, we first considered the directed weighted network formed by association norms, where nodes are words and edges are directed from cue to target word, with a weight equal to the association strength (that is the probability of that target word being produced when this particular cue is presented). This network is of particular interest since it lets us define features that reflect the associations driving false memories in word lists (Deese, 1959), a phenomenon which may be involved in the transformation of quotations.

We used three standard measures on the FA network:

- **Incoming degree centrality**, measured by the number of cues for which a given word is triggered as a target, and a corresponding generalized measure, node **Pagerank** (Page, Brin, Motwani, & Winograd, 1999), which has already been used on the FA network by Griffiths et al. (2007). In the present case these two polysemy-related measures are quasi-perfectly correlated.⁸

- **Betweenness centrality**, another measure of node centrality describing the extent to which a node connects otherwise remote areas of the network (Freeman, 1977). This quantity tells us if some words behave as unavoidable way-points on association chains connecting one word to another.⁹

- **Clustering coefficient**, which measures the extent to which a node belongs to a local aggregate of tightly connected nodes (Watts & Strogatz, 1998), computed on the undirected *weighted* version of the FA network.¹⁰ This tells us if a word belongs more or less to a local aggregate of equivalent words (from a free association point of view).

Variable correlations. Several of these features are strongly related and can be grouped together. To make corre-

lation values as well as future comparisons more reliable, we log-transformed features that have marked exponential distributions (a few words valued orders of magnitude higher than the vast majority of other words).¹¹

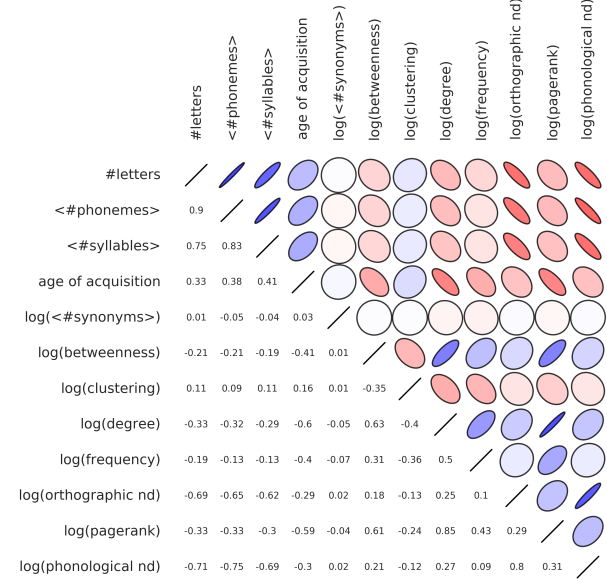


Figure 1. Spearman correlations in the initial set of features

The pairwise correlations in the initial set of features appears in Fig. 1. By looking at absolute values, three subsets of highly correlated features can be easily identified: (a) number of letters, phonemes, and syllables with pairwise correlations greater than .75; (b) orthographic and phonological neighborhood densities, with a correlation of .8; (c) age of acquisition, betweenness, degree, and pagerank centralities, with absolute pairwise correlations at .41, .6, .59, .63, .61 and .85. Applying a feature agglomeration algorithm targeted at

⁸Note that in-degree does not take the weights of links into account, as it counts 1 for each incoming link. Pagerank on the other hand, does take the weights into account.

⁹For this measure, weights are interpreted as inverse cost: the stronger a link, the easier it is to travel across it. A stronger link will be favored over weaker links in the computation of the shortest path between two words.

¹⁰The Clustering coefficient is formally defined as the ratio between the number of actual versus possible edges between a node's neighbors; this is poorly defined in the case of directed networks, which led us to ignore the direction of links in the network for this measure (if two words are connected in both directions, the weights of both links are added to make the final undirected link's weight).

¹¹The distributions of original and log-transformed features appears in the supplementary material, along with correlation scatter plots for each feature pair, summarized below with correlation values.

6 groups refined this observation by producing identical (a) and (b) groups, a (c) group without betweenness centrality which was instead assigned to a group (d) with clustering coefficient, and the remaining features (frequency and number of synonyms) as singletons.¹²

Since our data is about written transformations, number of letters and orthographic neighborhood density are the natural representatives of groups (a) and (b) respectively. Given the importance of age of acquisition in the lexical feature literature, we chose it to represent group (c). Finally we used clustering coefficient to represent group (d) since it has already been used in previous studies. The final set of features we will discuss in the rest of the paper, as well as their cross-correlations, can be seen in Fig. 2 (the analysis on the complete set of features can be found in Supplementary Material).¹³

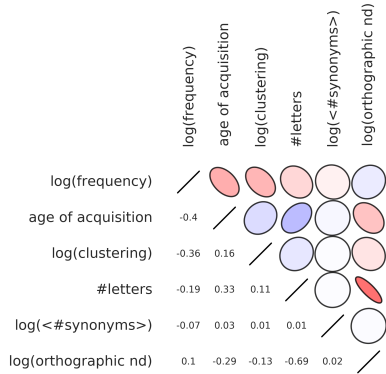


Figure 2. Spearman correlations in the filtered set of features

Substitution model

#19: show more clearly why this is more robust with single-substitution, justifying our choice of this case

#17: explain all models and the work involved, with graphs and explanatory figures for each model in annex

We finally need a substitution detection model, for the utterance data we use presents a challenge: quote-to-quote transformations, and much less substitutions, are not explicitly encoded in the data set. More precisely, each set of quotations bears no explicit information about either the authoritative original quotation, or the source quotation(s) each author relied on when creating a new post and reproducing (and possibly altering) that source. We thus face an inference problem where, given all quotations and their occurrence timestamps, we should estimate which was the originating quotation for each instance of each quotation.

We therefore model the underlying quotation selection process by making a few additional assumptions. The main issue is deciding whether a later occurrence is a strict copy of

an earlier occurrence, or a substitution of an even earlier occurrence, or perhaps even a substitution or copy from quotes appearing outside the data set, that is from a source external to the data collection perimeter.

Let us give an example: say the quotation “These accusations are false and **absurd**” (q) appears in a blog on January 19, and the slightly different quotation “These accusations are false and **incoherent**” (q') appears in other blogs twice on the 20th and once on the 21st of January. If q was sufficiently prominent when q' first appeared, we can safely assume that the first author of q' on the 20th based himself on q as is shown in Fig. 3a. But what about the second and third occurrences of q' , on the 20th and 21st? Should we consider them to be substitutions based on q or accurate reproductions of the previous occurrences of q' ? (Options shown in Fig. 3a.)

To settle this question we group quote occurrences into fixed bins spanning Δt days (1 day in the implementation), each one representing a unit of time evolution. When a quotation q' appears in bin $t + 1$, it is counted as a substitution if it differs from the most frequent quote q of the preceding bin t (or a substring thereof) by only one word. If not, q' is not considered to be an instance of substitution. Note that these assumptions are admittedly a subset of a much wider set of possibilities, each leading to alternative substitution inferences.¹⁴ It is however not feasible to try them all and, for the sake of simplicity, we decided to go with a sensible set of assumptions, and stick to them without trying alternative options.

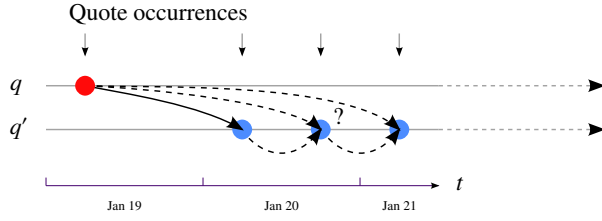
#12: fix substitution counts and add precision/recall

Put shortly, such a model defines how many times quote occurrences can be counted as substitutions: in Fig. 3b, occurrences of q' on the 20th are counted as substitutions, whereas the occurrences on the 21st are not. In practice, from the 2.43m initial occurrences spread into 45,749 classes of quotes, with significant redundancy (many quotes are indeed simple duplicates), we manage to mine 6,172 real sub-

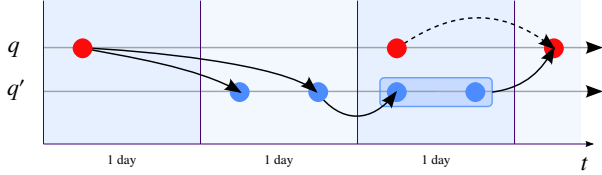
¹²Agglomerating into less than 6 groups merged groups (a) and (b), which we excluded to keep neighborhood densities in their own group; agglomerating into more than 6 groups separated age of acquisition from group (c), which we excluded given its high correlation values to the rest of group (c). We used scikit-learn’s FeatureAgglomeration class for this procedure (Pedregosa et al., 2011).

¹³Note that feature values stem from different data sets which do not always encode the same words. Indeed, we have data on frequency for about 33.5k words, on age of acquisition for 30.1k words, on clustering coefficient for 5.7k words, number of synonyms 111.2k, and orthographic density 17.8k words. Quite often then, not all features are available for all words in our data set; however this is not problematic since the analysis is done on a per-feature basis, and not all words need be encoded in all features.

¹⁴In particular, the criterion of the most frequent quote in the preceding bin may be replaced with the most frequent quote overall, or the oldest quote; time can be sliced into fixed bins as is done here, or kept fine-grained by using sliding bins.



(a) Possible paths from occurrence to occurrence



(b) Binned quotation family with majority rule

Figure 3. Temporal binning of quotation families. q and q' are two versions of a quotation belonging to the same cluster. In the bottom panel (b), q' holds the majority in the 3rd bin and is considered the unique basis for the last occurrence of q (in the 4th bin). This is despite the fact that q also appears in bin 3 alongside q' , and despite it having appeared earlier at the very beginning of the quotation family (indeed in the situation shown in Fig. 3b, this seems to be the most likely scenario). Conversely, if q had been the most frequent quote in bin 3, the last occurrence of q in bin 4 would have been considered a faithful copy of the occurrence of q in bin 3.

stitutions obeying to this model. From these substitutions we remove those featuring stop words, minor spelling changes (e.g. center/centre, November/Nov, Senator/Sen), abbreviations, spelled out numbers; this eventually yields 1,051 valid substitutions.

Note that our minor-spelling-changes exclusion does not affect orthographic nd: in a sample of 100 substitutions, no rejected substitutions are minor orthographic changes that would interest us (they're always different spelling of the same concept).

Results

#16: add a quick description of what types of substitutions we see, then moving on to the observables since it's not what principally interests us.

We may now use this substitution model to formulate a family of psycholinguistic hypotheses describing the role of each feature in the accuracy of the reformulation. To this end, we build two main observables for each word feature. First, we measure the susceptibility for words to be the target of a substitution in a quote, knowing that there has been a variation, in order to show which semantic features are the

most likely to “attract” a substitution under this condition. Second, we measure the change in word feature upon substitution, looking at the variation of a given feature between start and arrival words.

Note that since we only consider substitutions and not faithful copies, we measure the features of an alteration *knowing that there has been an alteration*, and we do not take invariant quotations into account. Indeed, in the former case we know there has been a human reformulation, whereas in the latter case it is impossible to know whether there has been perfect human reformulation or simply digital copy-pasting of a source (“CTRL-C/CTRL-V”). Furthermore, perfect human reformulation possibly involves different practices than those involved in alteration — for instance drafting before publishing, double-checking sources, proof-reading — and may not be representative of the cognitive processes at work during alteration. The two situations are different enough to be studied separately, and we focus here on the latter.

Susceptibility

#19: explain if we're susceptible to bias from single-substitution

We say that a word is *substitutable* if it appears in a quote which undergoes a substitution, whether that substitution operates on that word or on another one. Word substitution susceptibility is computed as the ratio of the number of times s_w a word is substituted to the number of times p_w that word appears in a substitutable position, that is s_w/p_w . In other words, it measures how often a word w actually gets substituted, compared to how often it could have been substituted (because it appears in quotes undergoing substitution).

Now, for a given feature ϕ , we obtain the mean susceptibility $\sigma_\phi(f)$ for the feature value f by averaging this ratio over all words such that $\phi(w) = f$, that is:

$$\sigma_\phi(f) = \left\langle \frac{s_w}{p_w} \right\rangle_{\{w|\phi(w)=f\}}$$

Put shortly, susceptibility focuses on the selection of start words involved in substitutions, measuring the effect of features at the moment preceding the substitution when it is not yet known which word in the quotation will be substituted.

#16: (1) show POS don't differ, (2) note that stopwords are excluded, which excludes POS open/closed discussion

#16: explain we do this on quartiles, rework results discussion

#16: explicit all significance claims, referring to the CIs

#17: show other feature variations and other models in annex

#15: relate to missed literature

Results for this measure are gathered in Fig. ?? . They first show an obvious strong effect of Word frequency: the

more frequent a word, the less likely it is to attract substitutions. Indeed, susceptibility goes from .33 for low-frequency words down to nearly 0 for very high-frequency words. To make things clear, this value of .33 means that low-frequency words, when present in a quote undergoing a substitution, are the ones being substituted 33% of the time on average.

The other features — Age of acquisition, Number of phonemes, Clustering coefficient and Number of synonyms — do not seem to exhibit any particularly significant effect on susceptibility. If we set aside the values for low Number of phonemes, for each of these features it is indeed possible to draw a constant line which always remains within the respective confidence intervals. If these variables have an effect, it is by no means as strong as it is for Word frequency. This is remarkably clear for Clustering coefficient and Age of acquisition, where susceptibility values remain within quite small intervals (respectively [.13 – .18] and [.16 – .20]). We may notice a slight effect for the lowest values of Number of synonyms and Number of phonemes, where the mean susceptibility is almost half as high as the average of the other values (respectively .09 vs. .16, and .11 vs. .17). Keeping in mind the poor statistical significance of this effect, we could still wonder if the shortest words and words with fewest synonyms are significantly less susceptible to substitution. To further examine this phenomenon, we plotted the two-dimensional map of susceptibility values for these two features (see heatmap at the bottom right of Fig. ??). Even if there are a few outlier cells, values tend to navigate around the mean value (.16) with little obvious regularity (except for a low number of synonyms, consistent with the unidimensional graph). On the whole, this makes it relatively hard to draw any conclusion as regards the direction of an effect, except for the least populated value ranges (which as a result are also less significant).

All in all, apart from Word frequency and despite some local tendencies, in general these results do not allow us to conclude to a marked effect of the selected psycholinguistic features on substitution susceptibility. We may therefore globally assume that substitution targets are chosen in a more or less uniform way with respect to these features.

Variation

We can thus show how words are modified once we know they are substituted, that is how their features are modified by said substitution. Considering a word w substituted for w' , we measure how the feature of w varies when it is replaced with w' , that is we look at $\phi(w')$ as a function of $\phi(w)$. Averaging this value over all start words such that $\phi(w) = f$ yields the mean variation for that feature value f , that is:¹⁵

$$v_\phi(f) = \langle \phi(w') \rangle_{\{w \rightarrow w' | \phi(w)=f\}}$$

Of prime interest is the comparison of the value of $v_\phi(f)$ with respect to f , as it shows whether there is an attraction (or

a repulsion) effect towards (respectively from) some values of each feature. In other words, plotting the $y = x$ line, we can see if substitutions tend to converge towards some typical value of a word feature or not — as is classically done in the study of dynamical systems.

We also introduce a null hypothesis \mathcal{H}_0 to compare the actual variation of a word's feature to its expected variation, assuming the arrival word w' was randomly chosen from the whole pool of words available in the data set for that feature.¹⁶ In this case, since $\phi(w')$ becomes a constant value in the above averaging (by definition w' does not depend on w anymore), the baseline variation under \mathcal{H}_0 may be rewritten as:¹⁷

$$v_\phi^0(f) = \langle \phi \rangle$$

This approach yields a fine-grained view of how word features evolve upon substitution, on average, with respect to (a) the original feature (vs. $y = x$) and (b) a random arrival (vs. v_ϕ^0).

#16: (1) add H00 lines to account for semantic similarity (nothing more fancy since it involves a threshold), (2) rework results discussion

#17: show other feature variations and other models in annex

#17: explain binning

#18: tone down claims about contractile: it's a possible hypothesis if this were the only process, but not observed with the mix of all other processes

#15: relate to missed literature

Results are gathered in Fig. ??. We can do a first striking observation: all graphs show the existence of a unique intersection of v_ϕ with $y = x$, while the slope of v_ϕ is smaller than 1, independently of the feature considered. In other words, beyond individual variation patterns, the substitution process is contractile for all the features, and each of them therefore exhibits a unique attractor. Second, the comparison with v_ϕ^0 shows that there are two classes of attractors, depending on whether:

1. there is a triple intersection (of $y = x$, v_ϕ^0 and v_ϕ);

¹⁵To avoid possible autocorrelation effects due to substitutions belonging to the same cluster (which are likely not statistically independent and may lead to overly optimistic confidence intervals), we first average substitutions over each cluster, by considering the average of arrival word features for a given start word.

¹⁶For instance, when considering the feature “Clustering coefficient”, the arrival word is randomly chosen among words present in the data set of FA norms.

¹⁷We additionally considered an alternative null hypothesis, denoted \mathcal{H}_{00} , where the arrival word is randomly chosen *among immediate synonyms of the start word*, that is an arrival word chosen among semantically plausible though still random words. In this case w'_{00} does depend on w . Our conclusions hold under this second null hypothesis, so for the sake of clarity we chose to keep the simpler \mathcal{H}_0 .

2. or v_ϕ always remains above or below v_ϕ^0 .

The first class (Number of phonemes and Number of synonyms) are features for which the substitution process only brings words slightly closer to v_ϕ^0 , and no uniform bias can be observed.

On the other hand, the second class (comprising Word frequency, Age of acquisition, and Clustering coefficient) are features for which the substitution process has a clear bias, positive or negative, with respect to the purely random situation (\mathcal{H}_0).

Word frequency, with v_ϕ always significantly above v_ϕ^0 , exhibits a strong bias towards more frequent words. This, in turn, is consistent with the hypothesis that substitution is a recall process, since common words are favored over awkward ones, while it goes against the idea that it could be a familiarity process, where awkward terms would be favored.

Age of acquisition and Clustering coefficient, on the other hand, exhibit a clear negative bias for the substitution process. Both curves are significantly below their respective v_ϕ^0 values, which is consistent with the literature on recall: words learned earlier and words with lower clustering coefficient are easier to produce than average (??). Clustering coefficient has the additional particularity that, on average, the destination word does not depend on the start word; that is on average, substitutions will always produce words with a clustering coefficient around $\exp(-2.4) \approx .1$.

To make things concrete, here is an example substitution taking place in the data set. At the end of January 2009, many media websites reported the following quote,

“The massive economic upheaval being experienced across the globe is sparing no one in the consumer electronics world.”

and a smaller number of media websites, and blogs, reported the following,

“The massive economic upheaval being experienced across the **world** is sparing no one in the consumer electronics world.”

The word *globe* is acquired at an average of 6.5 years old, appears about 3.5k times in the data set, and has a Clustering coefficient of .24. The word it was replaced with, *world*, is acquired on average at 5.3 years old, appears about 146k times in the data set, and has a Clustering coefficient of .05. (Both words have four phonemes.) Such a change, though minor in appearance, is a typical example of alteration along the lines shown by our results.

#16: add the taking-context-into-account parts, potentially moving the non-relative results discussions to here: (1) explain and add sentence-relative susceptibility by quartiles, which has a perfectly clear interpretation + results discussion, (2) explain and add sentence-relative variations + results discussion (3) link those results to non sentence-relative values

#17: show other feature variations and other models in annex

#15: relate to missed literature

We thus observe a clear convergence pattern for each feature, with two different classes corresponding to the psychological relevance of each feature for the substitution process. Taken as a dynamical system where substitutions are repeatedly applied, Number of phonemes and Number of synonyms will simply converge towards their average value in the FA corpus (i.e. v_ϕ^0), while Word frequency, Age of acquisition and Clustering coefficient, consistent with the literature, will converge towards significantly biased values indicated by the intersection with $y = x$ (respectively, a frequency of $\exp(9.1) \approx 9000$, an acquisition age slightly below 8, and a Clustering coefficient of .1).

Discussion

Discuss related to introduction. Attractors, lineage with specification, what we couldn't observe, how it fits into Kirby.

#15: relate to missed literature

ADDTHIS: We also chose exploratory vs. predictive to give a detailed view of what happens and because there's too many possible things to predict.

ADDTHIS: By characterizing substitutions with 6 features on the disappearing and appearing words, we identify what makes a substitution more likely, and how a word changes when it is substituted. Consistent with known effects in linguistics, we observe that low-frequency words and words learned later in development are more susceptible to substitution than other words. Looking at the context those words appear in, we observe a marked effect for substitution of extreme words in a sentence (either very high-valued or very low-valued features compared to sentence average, except for word frequency). Focusing on how words are transformed, we see that the appearing words have significantly higher frequency and lower age-of-acquisition than synonyms of the disappearing word. Finally, the patterns we observe are also consistent with an attraction of each of the features towards a (feature-specific) asymptotic value.

ADDTHIS: It is possible however, that these attractors appear due to an interaction between biases and sentence context, making it a contingency rather than a rule. This is not really dealt with (context, aside from relevance) by Sperber.

Attraction can also be defined on any number of dimensions. It can be on the structure, on anything, so saying there could be an attraction while not specifying the dimension is really meaningless. What's more important is to look at a specific dimension, and see if there's attraction on that one, as we did here for features.

We could've done also on semantic grouping, predicting the new word based on semantic similarity (or on frequent

dyads, i.e. collocation with previous word the same way Zaromb et al. 2006 explain PLIs), and predicting the disappearing word based on the cost of doing such a substitution (lower cost -> higher prob of substitution). The point is, there's decades and many fields of psycholinguistics, and we can connect each of them with this question.

All of this is possible with our software that we published.

ADDTHIS: Taking context into account is more than what we did. For instance, building on Zaromb 2006, you could imagine that the substitutions appear because the word preceding the substituted one appears in another dyad a lot more than this one, triggering a substitution (Zaromb's associative vs. contextual retrieval processes in recall).

ADDTHIS: Soooooooo... following literature on word lists (Zaromb and DRM): - we could predict the new word in substitution? Take the strongest average association to words in the sentence. - we could predict substituted word? Take the word following the one that triggers the new word. Problems: - we probably won't find the exact word, but one similar to it (even Zaromb can't predict the exact word, they don't try, they just check it comes from the right list). How to evaluate that? - if computing LSA/LDA on the corpus (which probably isn't adapted because of the short sentence nature of the data -> topics = quote families), it's tautological unless you suppose substitutions have a negligible effect. Explain that to the reviewer.

Again justify our approach w/ features by the shape of our data: few substitutions per cluster (avg. 9), and substitutions on relatively few clusters overall -> opposite situation to a few lists repeated through 50 subjects where frequency of transition has meaning. Here for each word, it's nearly one shot. So we have to categorize words (by using low number of features -> known features best) to get frequencies. From there, you can predict many many things, so better describe.

Concluding remarks

#14: link to introduction discussion: (1) this can be a model system, (2) convergence can be looked for in any dimension, but that doesn't make a theory, so Epidemiology of Representations is all nice, but: (3a) taken simplistically it predicts obviously simplistic stuff (all quotes CV. to a single quote), (3b) taken more realistically (many dimensions in life) it gives some ideas, but it's not clear it's a core principle (3c) we need more controlled investigation to fuel the discussion and see how relevant it is.

ADDTHIS: On the other side an enactive proposition which anthropologists like Ingold, in line with Mauss' works, are calling for [Citation needed], is being developed by Froese, Di Paolo, and De Jaegher among others [Multiple citations needed].

The question is also gaining relevance in other fields, as work in evo-devo and non-genetic inheritance is accumulating evidence not accounted for by the modern synthesis

[Citation needed]; these discoveries are creating demand for new or extended approaches to life evolution that unify its different levels, as well as creative empirical methods to test the predictions these approaches make [Citation needed].

We aimed to contribute to the empirical understanding of representation transformation processes by studying a simple task where individuals are *implicitly* trying to reproduce textual content. To some extent, our work amounts to a large *in vivo* experiment where we appraise the impact of classically-influent psycholinguistic variables in the accuracy of the reproduction. In more detail, we describe the joint properties of the substituted and substituting terms in the reformulation by individuals of a specific type of utterances (quotations).

#18: tone down claims about contractile: it's a possible hypothesis if this were the only process, but not observed with the mix of all other processes

For each of the selected psycholinguistic variables, we demonstrate the existence of attractor values in the underlying variable spaces. More precisely, beyond the interpretation of our results for each variable, we notice that all variables remarkably exhibit a single attractor and are generally contractile — as such, even though the observed convergence patterns only partially explain quotation evolution, we shed light on a class of phenomena which are susceptible to constitute a key element of a broader empirically-grounded, attractor-based theory of cultural evolution.

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