

PhD thesis précis

# Epidemiology of representations : an empirical approach

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## 1 Introduction

Recent years have seen several attempts to bring cognitive science and social science together. "Social cognition", "cognitive economy" and "cultural evolution" are examples of such fields having recently emerged, approached from multiple viewpoints and involving a variety of disciplines. This thesis focuses on an approach formalised by Dan Sperber in the mid-nineties: in a series of innovative articles gathered in (Sperber 1996), the author proposes a research program called *Cultural Attraction Theory* (henceforth CAT), which aims to provide the cognitive and social sciences with a common framework to address interdisciplinary questions. Since its initial introduction, this proposal has grown into one of the two main cognitively-inspired approaches to understanding the way a community's culture evolves over time due to mechanisms at the inter-individual level (the other approach being Standard Cultural Evolution, Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981). These approaches, now "a booming cottage industry on the borders of evolutionary biology, archaeology, and biological anthropology" (Sterelny 2017), also propose a way of combining works from anthropology, cognitive science and evolutionary biology, disciplines that have remained isolated from one another for too long.

CAT is explicitly not a reduction of one of these fields to the other. Nor does it claim to be a grand theory unifying all the disciplines studying life under one umbrella. Instead, it creates bridges between cognitive science and anthropology so that the two can eventually work together in a common formulation of their questions. To do so it proposes a general ontology where culture is thought of as a collection of representations: representations can be either public, for instance a picture, a public speech, or this précis, or they can be mental (as those theorised by cognitive science), when someone interprets a public representation that they are perceiving. CAT suggests that the culture of a society can be modelled as a large dynamical system of representations being constantly interpreted into mental versions, and produced as new and trans-

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formed public representations. A central question then appears: given the significant changes that representations undergo each time they are interpreted and produced anew, how is it that culture can be so stable over time? The cultural attraction approach answers this question by proposing that, due to the interaction of the cognitive processes and contextual factors at play when representations are transformed, the dynamical system that models a society should have attractors. These *cultural attractors* are CAT's main concept for explaining the stability of culture over time.

The hypothesis of cultural attractors is interesting for at least two reasons. On one side, it provides intelligibility into culture and its processes of change. On the other side, it incorporates a central claim of the theory, namely that cognitive processes play an important role in the way culture evolves over time. Empirically validating the existence of such attractors has thus become a major goal for the theory, but doing so has proved itself challenging. Up to now, empirical approaches to the question have fallen into three broad categories, each of which has some limitations. The first is to simulate the evolution of representations in the laboratory, be it through iterated language evolution (see Tamariz and Kirby 2016, for a review), or through so-called transmission chains used to study the evolution of objects such as short audio loops (MacCallum et al. 2012), risk perception (Moussaïd, Brighton, and Gaissmaier 2015), or abstract visual patterns transmitted by apes (Claidière et al. 2014). The second approach is to compile historical and anthropological works on a given subject to reconstitute the evolution of a type of representation as documented. This technique has been used by Morin (2013) in his study of how painted portraits change over the centuries, and by Miton, Claidière, and Mercier (2015) in their examination of the practice of bloodletting. The third approach is to study the evolution of representations in online social networks.

The wide array of disciplines studying these complementary questions, and the variety of techniques used in the process, testify to a major obstacle: collecting relevant data in usable amounts to analyse cultural evolution is not easy. Indeed, the works cited above invariably leave core aspects of the question aside: transmission chains operate on extremely simple representations; recompiling historical and anthropological works uncovers trends with many explanations competing for causality; models of online content propagation overlook cognitive levels of explanation by and large. It is possible, however, to combine the advantages of these techniques into new methods that significantly expand what empirical studies can tackle. By applying the tools of psycholinguistics to the study of online communities on one side, and enabling transmission chains to benefit from widespread computing power and internet infrastructure on the other side, we are able to collect massive amounts of usable data for the empirical and quantitative study of out-of-laboratory epidemiology of representations.

Our practical goal in this thesis, then, is to introduce new empirical methods which combine the strengths of existing approaches, and can contribute to the validation of cultural attractors. The more general goal is to contribute a detailed empirical study case to CAT, which we focus on linguistic utterances. Indeed, linguistic traces of online interactions are readily available and easy to collect, such that it is possible to assemble data sets of useful size and quality for the study of this case. Second, aside from providing an extremely versatile type of representation that makes the question of transformations interesting in itself, language is also at the core of several criticisms opposed to CAT. Linguistic utterances are therefore a good use case to contribute to the debate surrounding CAT. The thesis presents two novel exploratory methods for the evolution of linguistic utterances, in which the detailed transformations can be observed, and the relevance of attractors in explaining the changes can be assessed. Both methods leave open the set of possible changes to observe, and work around the limitations of previously isolated approaches.

Our experiments elicit significant and detailed biases in the way utterances are transformed, with overall trends that are consistent with the existence of attractors at the level of lexical word

variables. Aside from the raw results that we uncover about the transformation of utterances, we contend that these experiments are useful in two other ways. First, they allow for a more precise formulation of the questions asked by CAT. Second, the experimental use of cultural attraction principles renders obvious the strengths and limitations of the approach for the case of linguistic utterances, and highlights new questions that should be explored by further research. In particular, we shall see that the exact definition, and thus the existence, of a cultural attractor strongly depends on the dimension at which we describe linguistic utterances, and that an account of how meaning is understood in context must be included in the theory to make further progress in the linguistic case.

## 2 Word substitutions in blogspace quotations

Our first case study introduces a data analysis approach which takes advantage of the ever-increasing avalanche of available digital footprints since the 2000's. Indeed, tools and computing power to analyse 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 artefacts across social networks has been studied in blogspace (Gruhl et al. 2004) and in emails (Liben-Nowell and Kleinberg 2008); Cointet and Roth (2009) described the reciprocal influence between the social network topology and the distribution of issues; Leskovec, Backstrom, and Kleinberg (2009) 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 et al. (2012) studied the characteristics of particularly memorable quotes that circulate in those networks. By mining similar data sets in a cognitive-aware manner, we believe it is possible to connect the field of cultural evolution with psycholinguistics, and thus advance the testing of cultural attractors.

To do so we analyse how quotes in blogs and media outlets are modified when they are copied from website to website. Indeed, such 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, and Adar 2011): authors spontaneously transform quotes, not only cropping them but also replacing words. For instance the quote "we will not be scared of these cowards" (a substring of a quote from former Pakistani President Asif Ali Zardari) is also found as "we will not be **afraid** of these cowards". More meaningful changes often happen too, such as the transformation of McCain's "I admire Senator Obama and his accomplishments" during the 2008 US presidential campaign, into "I **respect** Senator Obama and his accomplishments". Since authors are implicitly required to copy quotes exactly, we can assume that most transformations, especially simple ones such as those shown above, are the result of automatic (i.e. hard to control) low-level cognitive biases of the authors.

We thus ask the following question: given such representations that seem to evolve precisely because of the kind of automatic cognitive biases evoked in Cultural Attraction Theory, do cultural attractors appear, and if so how do cognitive biases participate in them? We chose to restrict our analysis to substitutions (i.e., one word being replaced by another), both to keep the analysis tractable and because of missing information in our data set.<sup>1</sup> While this limits the scope of our results to the particular data set we use, the methodological point we also make is left intact. By characterizing words using 6 well-studied features, we show that authors preferentially substitute words known for being harder to recall: most prominently words with low

<sup>1</sup>As explained in the thesis, 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.

frequency (Gregg 1976), learned later (Dewhurst, Hitch, and Barry 1998), or made up of more letters (Nickels and Howard 2004), both globally and in comparison to the sentence they appear in. Further characterizing the substitutions by examining the variation of word features from disappearing to appearing words, we show: (a) that the operation is contractile on average, that is, a transformation will usually bring words closer to an attractor point on each feature, much more than what a semantically plausible but random process would do; (b) that authors produce words that are easier to remember than the synonyms of the disappearing word (a fact that is reflected in the position of the attraction point). In other words, the substitutions behave consistently with the existence of feature-specific attractors, and their behaviour cannot be explained by assuming that words are simply replaced by random synonyms.

Unfortunately we do not actually observe quotes converging on a global scale towards attractors in their various dimensions, as the limits of the data set do not allow us to infer chains of substitutions. Furthermore, substitutions themselves are not the only type of transformation at work in the data set (however both these points are addressed in the next chapter). Nonetheless, these findings (a) bring light to this simple type of transformation, and (b) elicit biases which are consistent with known psycholinguistic effects, with the hypothesis of cultural attractors in representations from everyday life, and with the hypothesis of lineage specificity which the iterated learning literature discusses (Claidière et al. 2014; Cornish, Smith, and Kirby 2013). As a whole, this first study can be viewed as analysing part of the transmission step operating in transmission chains of artificial languages like those studied by Kirby, Cornish, and Smith (2008), yet with natural language out of the laboratory. It works by successfully applying knowledge from cognitive science to real-life complex data, a task that remains a challenge in the study of cultural evolution. More broadly, we believe that applying such data mining tools to manage the complexity of real-life data is a promising approach for the joint analysis of cognitive science and culture.

### 3 Transformations in large-scale transmission chains

Our second case study aims to remedy several caveats of the previous chapter by studying the evolution of short utterances in a controlled experimental setting. Indeed, the online corpus only let us examine simple transformations, remained at the low level of lexical properties such as word frequency and age of acquisition, and did not let us identify chains of transformations. In this chapter therefore, we develop a novel online and controlled experimental setting: while the situation will be somewhat less ecological, it will allow for the collection of all the necessary data for a deeper analysis.

Here too, our approach is exploratory: our goal is to construct a descriptive model of the process that can bring insight into why utterances change the way they do, and how such observations can be connected to current knowledge in linguistics, on one side, and to the broader cultural evolution frameworks, on the other. Indeed, current knowledge of the transformation of utterances is quite partial: laboratory transmission chains show that a number of high-level biases appear in the transmission of purposefully constructed complex stories, but do not explain in detail how such trends come about. On the other hand, the psycholinguistics literature on sentence recall shows that there are important semantic and syntactic effects in the way sentences are reformulated, but they do so on extremely simple types of content that make it difficult to generalise results. There seems to be a missing link that could connect the high-level effects that are observed in transmission chains of complex stories with the lower-level processes that are known to act in the recall of simple sentences. A descriptive model of transformations would go a long way in creating this link, and would make it much easier to explain the overall evolution

of utterances in terms of lower-level cognitive mechanisms.

In order to collect a sufficient amount of quality data, we chose to run a set of transmission chain experiments on an online platform developed for the purpose: indeed, after an initial development phase, the web-based experiment approach lets us collect large amounts of data in short periods of time, while maintaining a level of control similar to that of laboratory experiments (Lerique 2016). In particular, it frees us from the limits of previous empirical approaches by combining three important properties:

- the use of realistic and ecological pieces of linguistic content (as opposed to the simplified sentences used in psycholinguistics, and to the minimal content types used in transmission chains);
- complete control over the data-generation process and its collection (as opposed to the analysis of large databases coming from online sources such as social media);
- the possibility for computational analysis, thanks to large-scale collection of quality data (contrary to most setups using realistic content), and the development of a specific technique for analysing transmission chains.

This approach let us run several large scale transmission chain experiments (up to 10 reformulations of each initial sentence with 140 participants), collecting complex and very high quality transformations (around 1% percent total spam rate) of a varied set of initial utterances. Our analysis is then geared towards creating an intermediary representation of the effect of transformations on utterances, one that is at a midpoint between the low-level of word features and the high-level of category contrasts, and which can be usefully modelled to better understand the evolution of utterance chains.

To this end we rely on a sequence alignment algorithm originating in bioinformatics, which we extend to the linguistic case, and further develop to be aware of synonyms and exchanges between separate parts of an utterance. Once correctly parametrised using a supervised training technique, we can decompose the transformations that subjects introduce into a series of elementary operations on each word or block of words: insertion, deletion, replacement, or exchange between subparts. This decomposition allows us to create a descriptive model and visualisations which are both general and precise in what they capture of the evolution of utterances along chains. Figure 1 illustrates such a visualisation.

We then quantitatively characterize the individual behaviour of each operation, as well as the dependencies between operations. Indeed, operations strongly depend on each other (e.g., insertions appear to make up in size for some of the deletions, while still introducing substantial change; in turn, deletions behave as a gating mechanism for other operations), and their prevalence also depends on the length of, and their position in, each utterance (longer utterances receive more operations; replacements preferentially target the interior of utterances, and insertions and deletions target the second half of utterances). The behaviour of each of these operations is also consistent with the biases identified in the previous chapter in terms of word features. Finally, we observe the overall evolution of the lexical makeup of utterances, which illustrates the attraction pattern on each lexical feature as previously hypothesized (see figure 2).

More broadly, we argue that this modelling approach provides crucial detail about the transformations, achieving a middle-ground between the focus on lexical features in individual word replacements and the wide-angle view of contrasts in the aggregated evolution of content along chains (the approach commonly taken in transmission chains). Indeed, it allows us to create a first descriptive model of the transformation of utterances, by bringing together the different base components of a transformation, and quantifying their behaviour and their dependencies.

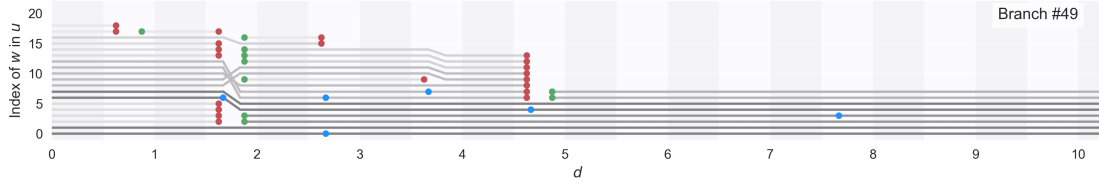


Figure 1: *Evolution diagram of an utterance along a chain.* The horizontal axis is the depth in the branch, and the vertical axis is the index of each word in its utterance. A grey line represents a word lineage along the branch, and the darkness of the line corresponds to lifetime of that word (darker lines indicate words that survive longer across transformations). At each depth, the darker background band indicates what the subject sees, and the lighter band indicates the transformation that the subject made. Inside lighter bands: red dots are word deletions, green dots are word insertions, blue dots are word replacements, and exchanges can be seen when bundles of lines cross each other. The initial utterance is «At Dover, the finale of the bailiffs’ convention. Their duties, said a speaker, are “delicate, dangerous, and insufficiently compensated.”» (Fénéon and Sante 2007); the final utterance is «in Dover at the bailiffs conventions something happened».

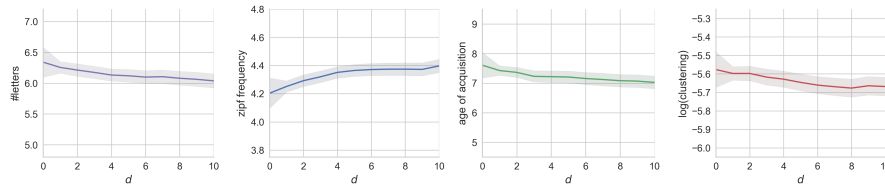


Figure 2: *Evolution of the average feature values of utterances along transmission chains.* Features are number of letters, log-frequency, age of acquisition, and log-clustering (a lower clustering value indicates a word that is semantically more differentiated). The evolution of each feature corresponds to a drift towards words known for easy recall in laboratory tasks.

Such a model, we argue, is an important step forward in creating a bridge between psycholinguistics and the study of cultural evolution.

## 4 Meaning in utterance transformations

So far we have considered the paradigm put forward by Cultural Attraction Theory, and sought to elucidate situations where linguistic representations are transformed as they are transmitted. We aimed to assess, on one side, the extent to which the empirical evolution of content agrees with what is expected under CAT, and on the other side, the extent to which CAT provides productive guiding questions in understanding what is at work in the situations studied. However, the case studies we presented did not bring us significantly closer to understanding the *semantic* changes that utterances undergo when they are transformed. In this last chapter we take a broader view on what would be necessary to achieve such a fuller understanding.

We begin with a manual exploration of the transformations observed in the previous chapter, showing that the surface measures that we used in quantitative analyses provide only limited insight into the evolution of the meaning of utterances. Indeed, meaning appears here as



a deeply context- and interaction-dependent property which cannot be understood by simply focusing on the utterances themselves; the lack of a definitive account of utterance meaning in CAT therefore renders the empirical question of attractors in this case under-specified. To make progress, we must broaden the scope of empirical studies of CAT beyond interactionless transmission chains and consider all interactions, either face-to-face or digitally mediated, and not necessarily linguistic.

We therefore discuss two important approaches to studying the meaning of utterances in relation to the context and interaction in which they appear: Relevance Theory and the Enactive approach. The first is more mature and better integrated with other areas of linguistics, and has a common philosophical basis with CAT. It bases its account of meaning on the symbolic processing of mental representations, and fleshes out the idea (first introduced by Grice 1989) that human communication is ostensive communication, based on the recognition of relevant communicative intentions which then enter inference processes in the mind. The second approach has grown more recently (Cuffari, Di Paolo, and De Jaegher 2015), and is philosophically based on authors who have strongly criticised representational approaches to cognition: it starts from a more bare-bones level of description, and proposes an understanding of meaning as endogenously generated through the interactions of organisms with their environment and other organisms. It avoids some of the issues with mental representations but has yet to tell a complete story for the study of language. Both these theories provide (part of) an answer to how agents select, infer or construct subtly varied meanings in the course of an interaction, but they do so by starting from opposite ends and building what is missing for their own account of meaning.

After a detailed presentation of both approaches and of their relationship to the questions of cultural evolution, we argue that the way forward lies in a healthy pluralism which uses both to explore complementary dimensions of the role of meaning in cultural evolution (in accordance with Chemero and Silberstein 2008), and avoids unnecessary scholasticism. Indeed, we believe that empirical investigation has an important part to play in such questions, leading us to close the chapter with some informed speculation on concrete experiments that could contribute to the study of meaning in cultural evolution.

## Conclusion

Taken together, we believe these works provide a significant step forward in empirical approaches to the study of short-term cultural evolution: they fill gaps in the current empirical exploration of CAT, detail two novel techniques that could be fruitfully reused and extended to improve empirical prospects, and extend further proposals for the semantic understanding of transformations. More proximally, they also create an accurate picture of the way written utterances are transformed in chains, providing a partial answer to how linguistic content might evolve as it spreads through a social network.

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