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Consensus under Constraints: Modeling the Great English Vowel Shift

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Abstract. Human culture is fundamentally tied with language. We argue that the study of language change and diffusion in a society sheds light on the cultural patterns, and social conventions. In addition, language can be viewed as a "model problem" through which to study complex norm emergence scenarios.
In this paper we study a particular linguistically oriented complex norm emergence scenario, the Great English Vowel Shift (GEVS). We develop a model that integrates both social aspects (interaction between agents), and internal aspects (constraints on how much an agent can change). This model differs from much of the existing norm emergence models in its modeling of large, complex normative spaces.

1 Introduction

A society can be viewed as a system of mutually-constraining norms. They range from simple norms like manners of greeting, to complex ones like marriage customs and rules for inheritance of property. These norms structure the way people interact by making behavior more predictable. Once established, they are generally self-reinforcing in that people prefer to conform, and violations are met with varying degrees of sanctions [1].

We are particularly concerned about the emergence of norms and language. We view language as a type of norm. Loosely speaking, norms are collective behavioral conventions that have an effect of constraining, structuring, and making predictable the behaviors of individual agents—that is, they are conventions that can exert a *normative force* that shapes individual agent behaviors—removing some behavioral possibilities from consideration and encouraging others—without

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a centralized “enforcement agency.” Existing models of norm emergence (e.g. [2, 3]) can be applied to linguistic cases. However, the language case introduces three intricacies that enrich the general study of norms:

Large Normative Option Space The multiplicative interaction between lexicon and grammar allows for an enormous number of possibilities. A population must converge on a shared lexical and grammatical convention within this very large space.

Complexly Structured Option States A language has many interactions between component elements, such as lexical and grammatical constraint. Thus language as a normative case is quite different from other convention phenomena studied earlier (e.g. [2]) that have a simple binary normative option space.

Ambiguity and Imperfect Knowledge Agents have no direct access to others’ preferred linguistic choices, but rather infer from limited samples. Again, this differs significantly from binary option spaces in which knowledge of other agents’ states can be inferred perfectly: $\neg 1 = 0$ and $\neg 0 = 1$.

The general aim of this research is to understand the impact of these three issues on the emergence of norms. In this paper we focus on studying the well known phenomena of sound change in language (such as the Great English Vowel Shift (GEVS) in England or the Northern Cities Vowel shift in the U.S. [4]). Modeling sound change requires addressing the intricacies listed above.

Section 2 describes the sound change phenomena and describes our Agent Based Model (ABM). Section 3 describes our simulation results; and Section 4 concludes with a discussion of future work and conclusions.

2 The Great Vowel Shift

While language changes continuously, at some points there have been large, significant changes in language, one of these is known as the *Great English Vowel Shift* (GEVS).

The GEVS took place roughly from the middle of the fifteenth century to the end of the seventeenth century. It was a change in the pronunciation of certain vowels; “the systematic raising and fronting of the long, stressed monopthongs of Middle English” [5]. For example, the pronunciation of the word “child” went from [čild] (“*cheeld*”) in Middle English to [čəɪld] (“*choild*”) to [čɑɪld] (“*cha-ild*”) in Present Day English.

The GEVS is often seen as an example of a *chain shift* – a situation where one vowel changes pronunciation, thus “creating space” for another vowel to “move up”. This causes a chained shift for a set of vowels – starting from a change by one vowel [4].

Figure 1 is a graphical depiction of the GEVS. The trapezoid is an abstract representation of the vowel space – the space of possible pronunciations of a vowel. The symbols represent vowels (in the standard *International Phonetic Alphabet* notation). Note that the topology of the vowel shift is linear, and thus we can model it in a linear array.

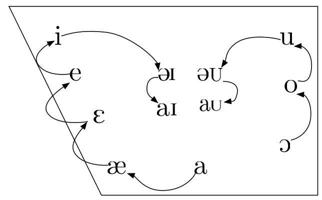


Fig. 1: The space of vowels, and the shift that occurred during the GEVS.

It is still not clear *how* the GEVS happened. Some theories suggest purely internal, linguistic factors; while others suggest that the interaction between different social groups with regional dialectal variations caused a shift [5–7].

Our objective in this work is to evaluate the latter theory using an ABM, and through it study the emergence of a norm in a complex system. We will show that a chain shift can occur as a consequence of the interaction of social and internal forces. Agents try to increase communicability with each other when they interact by trying to align their pronunciations (social), but are constrained by a *phonetic differentiability* requirement, i.e. they have to maintain sufficient *spacing* between their phonological[4] categories to be able to distinguish the vowels from each other (internal). The interplay of these two processes leads to a chain shift.

2.1 A Model of Population Wide Language Change

The ABM will have *agents* that represent individuals; each agent has a language that represents vowels and their pronunciations. Agents will be embedded in a social network that determines who the agents can interact with. In the next section we describe the model.

A language will consist of 5 vowels, represented as 5 variables $\{v_0, v_1, v_2, v_3, v_4\}$. The pronunciation of a vowel is characterized by the principal frequency components of the sound. The lowest frequency component is called the "first formant", the second lowest is the "second formant", etc. Due to the low resolution of human perception the first two formants chiefly disambiguate a vowel [8]; for simplicity we focus on a single formant model, following [9]. Each vowel can take on an integer value between $0 \ldots (q-1)$ which represents the possible values of the first formant.

A language must satisfy the following constraints:

Phonetic Differentiation Constraint The vowels (in a vowel system) should have pronunciations that vary enough to allow reasonable differentiation between them. Intuitively, if two vowels are very similar they will be mistaken for each other. Two vowels x, y are said to be *differentiable* if $|x-y|-1 \geq d$ for $0 < d < q$.

[4] *Phonetics* refers to the study of the (continuous) sound signal; *phonology* refers to the study of the (discrete) categories into which this signal is perceptually mapped.

Ordering Constraint There is a total ordering on the vowels. This means that two vowels cannot swap their locations, $v_i < v_j \forall i, j \; s.t. \; i < j$.

At each time step in the simulation we simulate an interaction between individuals via a *language game* [10] – an interaction in which agents exchange knowledge of their language with each other. Agents change their language as a result of these interactions.

A language game consists of two agents, a speaker (a_s) and a hearer (a_h). One of the five vowels is chosen as the *topic* of the game. The speaker then communicates to the hearer the value of this vowel. The hearer changes the value of its own vowel to match that of the speaker while still satisfying the constraints described above. If matching the speakers vowel would violate the constraints, the hearer does not change at all.

Note that this seemingly unrealistic interaction is an abstraction of a more natural interaction, where an agent utters a word that contains the vowel which we are calling the topic above. Further, it is generally possible to guess the word from context, even if the vowel pronunciations of the two agents disagree. Thus, we assume that the hearer knows both which vowel the speaker intended to utter, and which one (according to the hearer's vowel system) he actually uttered. The hearer then changes his own vowel system based on this information and the constraints below.

3 Simulation Results

We implemented the model presented above and evaluated three scenarios. All simulations used the following settings: $n = 1000$, $m = 5$,$q = 30$, $d = 4$. To simulate social hierarchies we array the agents on a scale-free graph. We used the extended Barabasi-Albert scale free network generation process [11]. The parameters were $m_0 = 4, m = 2, p = q = 0.4$.

Experiment 1: Consensus to a fully solved configuration In the first experiment we investigated the emergence of a common language from random initial conditions. The population was initialized with randomly chosen assignments of vowel positions (that respect the ordering constraint but not the phonetic differentiation constraint).

Figure 2a shows time on the x-axis, and the average value of each vowel (over all agents in the population) on the y-axis. We see that the lines corresponding to the vowels become completely flat as the simulation progresses, and then stay that way. This demonstrates the emergence of a stable state. Further, the vowel positions are widely separated, which shows that the phonetic differentiation constraint is being satisfied.

Experiment 2: A New Subpopulation For the second experiment we looked at the introduction of a new population of agents with a different language. This is similar to the sudden immigration of new language speakers into a country. Will the introduction of a new population cause a chain shift in the pronunciation of vowels?

In this experiment we replaced 30% of the population with a new population initialized with a different state. Initially, all agents had state $[0, 5, 10, 15, 20]$. The introduced population had state $[5, 10, 15, 20, 25]$, which is an overlapping but different state that satisfies the constraints. The entire vowel system is shifted by five positions with respect to the existing vowel system. The new population replaced the lowest degree 30% of nodes in the graph and was introduced at time step 1000. Figure 2b show the first 30K time steps.

Interactions between the new population and existing agents immediately start to cause a shift in the vowel positions. However, the vowels do not start shifting all together – the first vowels to shift are v_0 and v_4, which move in opposite directions. These are followed in turn by v_3 and v_2 (in the direction of v_4), while v_1 ends up staying more or less stable. Figure 2c shows the long run behavior of the same experiment. We see from this figure that eventually the entire population converges on a new stable state $[0, 5, 15, 20, 25]$, which is a combination of the vowel systems of the two populations. Further, the emergence of this new vowel system occurs through a chain shift, in two directions – v_0 moves down, while $v_4, v_3,$ andv_2 move up, in that order.

Experiment 3: Varying the Social Network

In the final experiment we replicate Experiment 2, however we modify the social network to see the effect of different topologies on time to agreement. We run Experiment 2 on three different social networks, Complete, Scale-Free and Small-World.

A complete network is a network that contains all possible edges between nodes.

A Small-World network is a network that has high clustering yet small characteristic path lengths [12]. The networks used in this experiment were generated using the Watts-Strogatz algorithm described in [12] with parameters $p = .1$ with an average connectivity of 12.

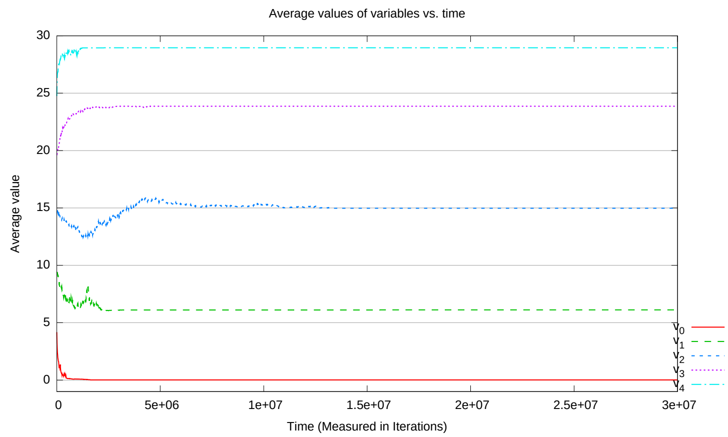
Figure 2 summarizes the results of the experiments. For each network 10 simulations were run where the network was regenerated according to the parameters above and the populations were reinitialized.

In all cases the system converged to a language satisfying the constraints, although the time till convergence varied. Figure 2 summarizes the results. Time till 90% agreement is a standard metric used in the literature [3]. It refers to the number of iterations till 90% of the population are in the same state.

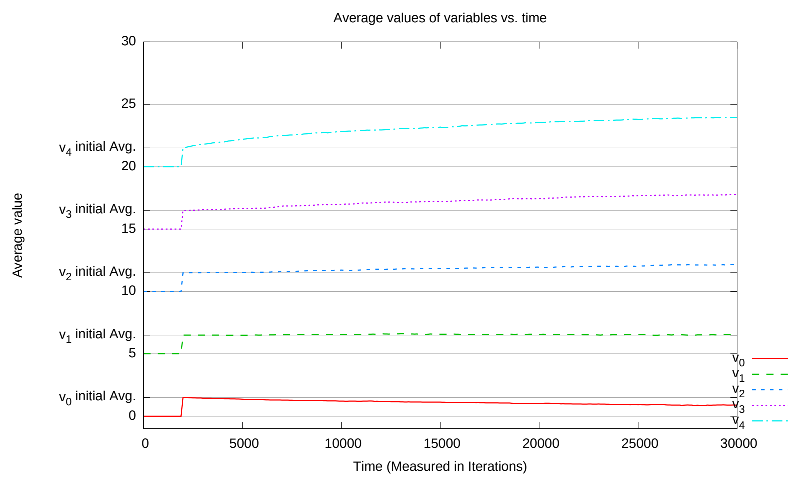
The results of these experiments concur with results from previous work on diffusion, albeit under simpler settings. [13] show that small world networks took longer to reach 90% agreement than scale free or complete networks for the majority-rule model. [14] describes similar results for the voter model. The means were significantly heterogeneous (one-way ANOVA, $F_{2,27} = 1.663, P = .208$).

3.1 Discussion

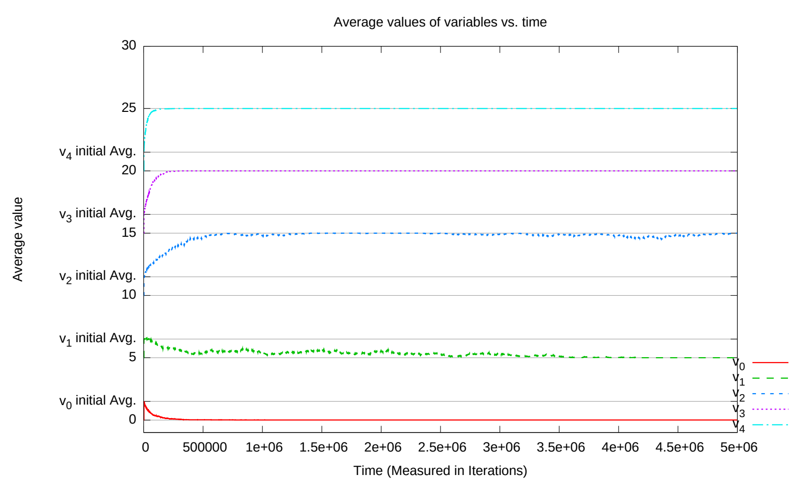
As discussed earlier, the vowel space in figure 1 can be "unfolded" into a linear array, in which the a → æ→ ɛ→ e → i → əɪ→ aɪ shift is a movement to the left, and the ɔ → o → u → əʊ→ aʊ shift is a movement to the right. This matches,



(a) Emergence of a consensus fully-solved configuration



(b) Initiation of the vowel shift.



(c) Coordination to a new state with a new introduced population.

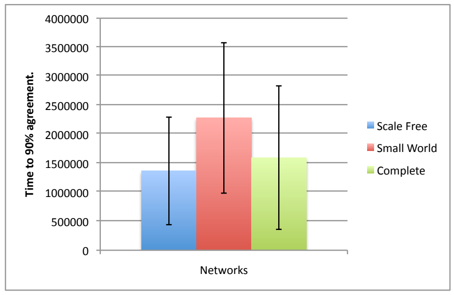


Fig. 2: Time till 90% convergence. Error bars indicate one standard deviation.

qualitatively, the movements observed in the experiments above, where some of the vowel positions shift up (to the left), and some shift down (to the right).

There are several competing explanations for the GEVS. One of the main contenders is that, after the Black Death there was a mass immigration into South-Eastern England, and the contact between the immigrants and locals led to a sudden change in vowel system. We have shown that this is a viable explanation, as it requires only the minimal assumptions that people tend to "accomodate" during interactions, i.e. they change their way of speaking to adapt to the other participant in the interaction, and that this accommodation is very limited, i.e. that they do not change their entire vowel system at once.

Taken together, the three experiments provide an interesting insight on norm emergence. Experiment 1 showed that a norm can emerge from a randomly initialized scenario.

Experiment 2 showed that the DCA framework could capture complex behavior such as chain shifting. In addition, as mentioned above, these simulations provide some insight into the immigration explanation of the GEVS.

Experiment 3 illustrates the similarity of norm emergence in this model with other models by comparing the time to converge. As seen in the literature, the results show that norms take longer to emerge in small-world networks than in scale-free or complete networks.

4 Conclusions and Future Work

The study of the emergence of norms in populations is an important aspect of social simulation. Norms are the means by which a society autonomously structures itself. The study of language norms is a difficult undertaking, however, because language as a system consists of an intricate web of relationships and constraints between several variables.

In this work we have presented a model to study linguistic change in population as an example of norm emergence in "complex" scenarios. Through empirical simulation we have shown that a sudden influx of speakers of a different language can induce a drastic sound change.

Furthermore, we viewed the impact of three social network topologies on the time to convergence metric. We found that results were similar to other model; the small-world network took the longest time.

There is much work that can be done to extend the current work. An account of the theoretical underpinnings of this framework remains to be developed, as well as extensions to other aspects of language, such as syntax. The idea of consensus under constraints is general enough, though, that we are confident that these goals can be achieved.

We have presented an approach to study consensus under constraints, and have shown that we can model phenomena of sound change such as vowel shifts. However, the same approach can, in principle, also be applied to any situation where we have a system of constrained variables over which consensus must be achieved.

References

1. Burke, M.A., Young, H.P.: Social norms. In Bisin, A., Benhabib, J., Jackson, M., eds.: The Handbook of Social Economics. North-Holland (Forthcoming)
2. Shoham, Y., Tennenholtz, M.: On the emergence of social conventions: modeling, analysis, and simulations. Artificial Intelligence **94**(1-2) (1997) 139–166
3. Delgado, J.: Emergence of social conventions in complex networks. Artificial Intelligence **141**(1-2) (2002) 171–185
4. Hock, H.H., Joseph, B.D.: Language History, Language Change, and Language Relationship: An Introduction to Historical and Comparitive Linguistics. Mouton de Gruyter (1996)
5. Lerer, S.: Inventing English: A Portable History of the Language. Columbia University Press (2007)
6. Leith, D.: A Social History of English. 2nd edn. Routledge (1997)
7. Perkins, J.: A sociolinguistic glance at the great vowel shift of english. Papers in Psycholinguistics and Sociolinguistics. Working Papers in Linguistics (22) (1977)
8. de Boer, B.: Self-organization in vowel systems. Journal of Phonetics **28** (2000) 441–465
9. Ettlinger, M.: An exemplar-based model of chain shifts. In: Proceedings of the 16th International Congress of the Phonetic Science. (2007) 685–688
10. Steels, L.: Emergent adaptive lexicons. In: Proceedings of the Fourth International Conference on Simulating Adaptive Behavior. (1996)
11. Albert, R., Barabàsi, A.L.: Topology of evolving networks: Local events and universality. Physical Review Letters **85**(24) (2000) 5234–5237
12. Watts, D.J., Strogatz, S.H.: Collective dynamics of 'small-world' networks. Nature **393**(6684) (1998) 440–442
13. Delgado, J., Pujol, J.M., Sanguesa, R.: Emergence of coordination in scale-free networks. Web Intelligence and Agent Systems **1**(2) (2003)
14. Suchecki, K., Eguiluz, V.M., Miguel, M.S.: Voter model dynamics in complex networks: Role of dimensionality, disorder and degree distribution. ArXiv (2008) cond-mat/0504482v1.