Preferential Attachment, Neutral Evolution and the Shape of Language Change

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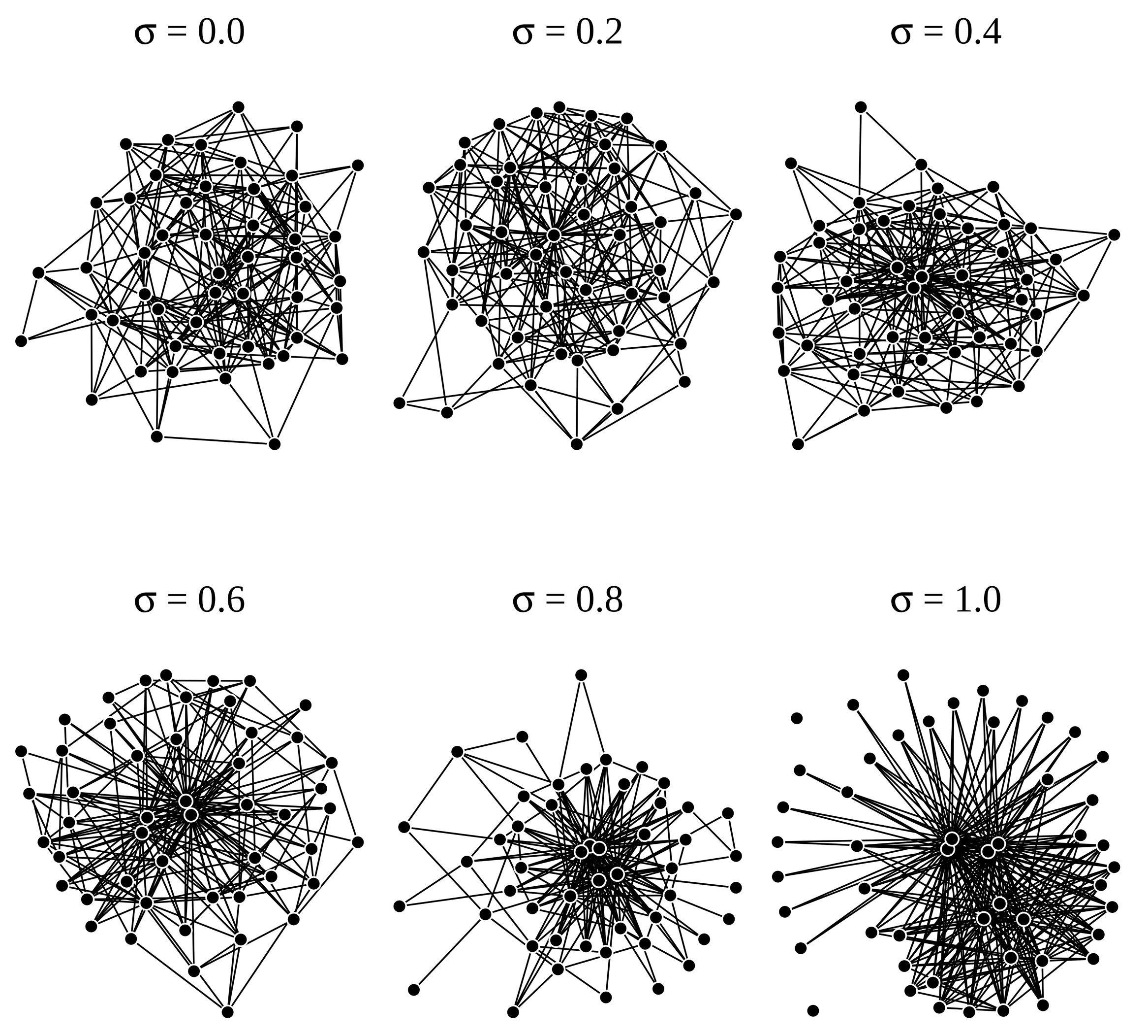

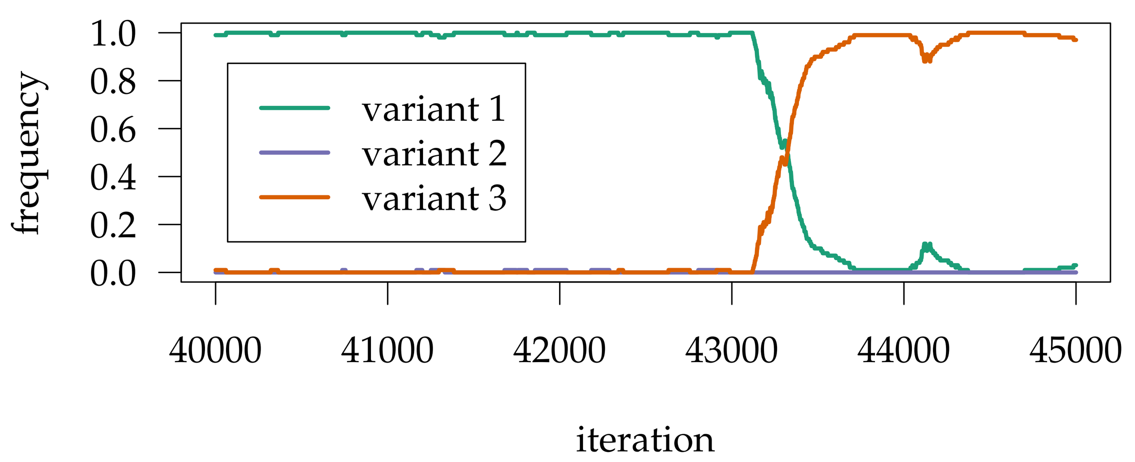

We say that a trajectory is **well-behaved** iff it satisfies the following conditions:

- **Dominance**: For most of the time, most of the speakers use one and the same variant;
- **Shifting**: Dominance notwithstanding, the community is able to shift from a state of dominance by one variant to a state of dominance by another variant;
- **Monotonicity**: These periods of change are 'smooth': the frequency of the receding variant decreases as a relatively monotone function of time, while the frequency of the innovatory variant increases monotonely.

These conditions can be quantified as follows:

- D = proportion of time in a simulation history that any one variant dominates, averaged across an ensemble of simulation runs;
- S = proportion of simulation runs in an ensemble of runs in which shifting occurs at least once;
- M_τ = a measure of monotonicity, defined as follows: we examine individual frequency trajectories through windows of length τ and determine how many times the frequency of variant i increases (m_i^+) and decreases (m_i^-) in such windows; averaging across variants, window placements and simulation runs we arrive at the quantity

$$M_\tau = 1 - \left\langle \left(m_i^+ m_i^-\right)^{1/2} \right\rangle / \tau,$$

which ranges from 0 (the most nonmonotone case) to 1 (monotone).

Putting these measures together we arrive at an overall measure of well-behavedness $W_\tau = DSM_\tau$, which ranges from 0 in the ill-behaved case to 1 in the well-behaved case.

For instance [4]:

Theorem 1 *Let $\sigma = 1$. Then the probability of a speaker with degree greater than K spreading their variant to at least one other speaker during their lifetime is*

$$q = 1 - \left(1 - K^{-1} + \mu\left(K^{-1} - C^{-1}\right)\right)^N;$$

this is bounded from below by $1 - e^{-1} \approx 0.63$ for $\mu < K^{-1}$. Moreover, q tends to 1 as $K \to 1$ and $\mu \to 0$.

Question. Can language change be **neutral**, i.e. not motivated by social, cognitive, articulatory or other biases (cf. [6])?

Problem. Previous computational studies [2, 3, 5] find that neutral selection mechanisms do not generate **well-behaved** (e.g. sigmoidal) propagation curves for innovatory linguistic variants: neutral change appears to be too 'random-walky'.

Solution. Previous studies have assumed a static network of speakers. We propose instead a generalized Moran model (cf. [8]) where speakers are **replaced** over time. More specifically, we assume:

- N speakers in a social network (links symmetric and binary);
- that each speaker entertains exactly one of C competing linguistic variants;
- that in a speaker replacement event the new speaker is given K links in the network
- that speaker attachment is controlled by a **preferentiality parameter σ** which serves to cluster the network: the greater σ, the more likely the new speaker is to be connected to speakers who are well-connected (cf. [1])
- that each speaker adopts their variant at the point they are attached to the network;
- that this adoption mechanism is frequency-driven in the speaker's neighbourhood (no biases towards adopting particular variants)
- that with (small) probability μ a random variant is adopted instead (innovation)

Good behaviour. It is then observed that the model exhibits a **punctuated equilibria** kind of dynamics, if σ is high enough: there is well-behaved change between semi-stable states in which one variant dominates.

This behaviour can be **quantified**, so that the 'well-behavedness' of a language community can be established computationally across a large batch of simulation runs and over extensive sweeps across the parameter space.

Results. We find (for $N = 100$)

- that **well-behaved neutral change** occurs for $\sigma \gtrsim 0.5$ and $K/N \lesssim 0.1$ and suitable μ;
- that this behaviour is independent of the number of competing variants C;
- that good behaviour is lost if the **rewiring dynamics is removed**

More **analytical work** allows us to understand why this happens in limiting cases of the model.

Conclusions. Contrary to the findings of previous computational studies on static networks, we find that well-behaved neutral change is a characteristic feature of dynamically rewired, clusterized networks of speakers. This **(1)** supports the hypothesis [7] that at least some processes of language change are inherently neutral and not driven by biases, and **(2)** indicates that future work in mathematical modelling of language change needs to take social network and finite system effects more seriously than has previously been done.

The model is simple enough to be reinterpreted as a more general account of cultural evolution.

References

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