Spatial theories of linguistic and cultural evolution

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Aims and objectives

Our aim is to develop minimal, experimentally verified spatial models of linguistic and cultural evolution. We believe that many processes which control linguistic and cultural change are inherently spatial in origin and operate on a wide range of scales. Although our methods are mathematical, the project can only be carried out in collaboration with linguists who have a deep understanding of the data that will inform our approach throughout the project and be used to test our theories. One possible impact would be for parts of linguistics to be made scientific by the incorporation of ideas from statistical physics. Beyond the lifetime of the project, the approach can extend to other non-linguistic phenomena that involve copying, possibly genetics. The project divides into three areas we believe will be important.

1. The nature and dynamics of interfaces between linguistic or cultural regions.
2. The connection between the "microscopic" (agent level) processes by which change takes place, and the macroscopic equations which describe large scale spatial evolution, and produce predictability.
3. The dimensionality, disordered structure, and changing form of the embedded social network through which language and culture propagate.

We will begin with 1 and 2 together and anticipate beginning 3 approximately one year in to the two year program.

1 *Interfaces* between linguistic or cultural regions

Throughout the 20th Century, both linguists and physicists have observed and studied interfaces in two dimensional systems. In physics, interfaces (*domain walls*) appear within regular, ordered structures of atoms as lines across which this ordering abruptly changes form. In linguistics the interfaces (*isoglosses*) are lines across which the common form of some linguistic feature changes. Considerable scholarship in linguistics has focused on describing the possible distributions and dynamics of these isoglosses, and T.B.'s work on Middle Norwegian has focused in part on trying to explain why different dynamics apply in different cases [3]. J.B. recently proposed that the two types of interface have a great deal in common mathematically [5]. If we assume that isoglosses feel a form of **surface tension**, as do domain walls in physics, then we can make remarkably accurate predictions about their spatial distributions (Figure 1).

Interfaces also provide an important mathematical link between small scale speaker interactions, from which they arise, and the large scale structure of the social network which is determined by the land mass shapes, geographical barriers and the distribution of people. The first question we will address is

How do population density and the traversibility of terrain affect the dynamics of linguistic and cultural interfaces?

J.B.'s theory is that interfaces are repelled by population centres [5] and that traversibility of terrain warps interfaces in a predictable way. Since this theory proposes diachronic mechanisms which produce predictable synchronic outcomes, it can be tested against synchronic sources such as linguistic atlas data. J.B. has recently defined a *director field* which measures the direction and magnitude of maximum linguistic change (see Figure 2), and may be easily computed from linguistic atlas data. If cities repel interfaces, then they will appear as points from which director field lines emanate. Terrain variations will distort the field in a predictable way. In disordered physical systems, interfaces typically become *pinned* (stuck). In the social context could a similar effect be created by the random nature of social contacts? Observation shows that although linguistic change typically follows an "S-curve" (slow at first, then accelerating, then tailing off) these sometimes exhibit a prolonged halt, especially in the early stages. We hypothesize that pinning effects may explain this.

2 From microscopic to macroscopic dynamics and large scale predictability

An open question is: by what mechanism do linguistic innovations diffuse spontaneously [4, 10] via an S-Curve? Do S-curves require that some new variants have a positive bias towards their uptake (i.e. positive social evaluation)

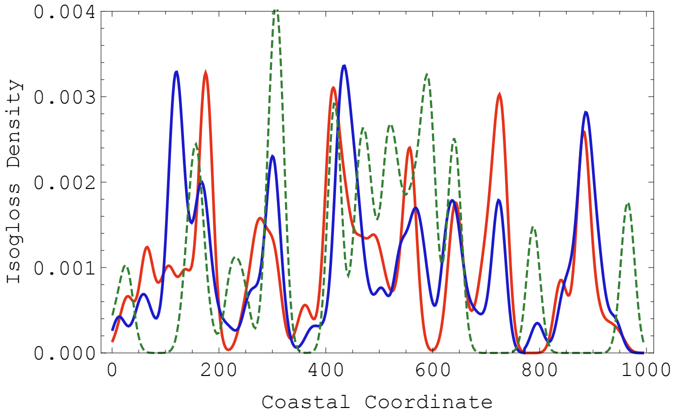

Figure 1: Blue line: density of isogloss coastal connection points calculated using the Survey of English Dialects [18]. Red line: predictions using surface tension theory. Green dashed line: null model which ignored coastline shape. (Burridge and Blaxter, unpublished)

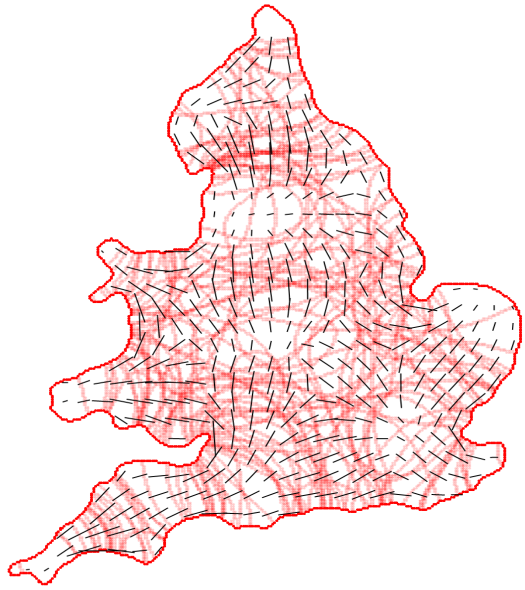

Figure 2: Red, semi transparent lines show simulated isoglosses. Black line segments show linguistic director field. (Burridge and Blaxter, unpublished)

or is bias not necessary? The debate is open because single community (non-spatial) models with and without bias are able to generate similar-looking S-Curves. We will address this question by "coarse graining" agent based models, defined on a network *embedded* in 2D space, to convert them into macroscopic models which are testable against spatial observations. If different microscopic models lead to the same macroscopic model, this will provide a method of model classification. We will infer the structure of the underlying network by comparing macroscopic models to time varying spatial data (e.g. [3]).

The process begins with an agent based model (Figure 3) where each speaker's state is (typically) defined by the frequency with which she uses one or more linguistic (or cultural) variables. We coarse grain by dividing the spatial domain into cells, and computing the dynamics of cell-averaged states ϕ_{xy} where (x, y) are cell coordinates. Provided average states vary slowly between cells, and the network is quasi two dimensional (geographical proximity is a good proxy for network proximity) then we can approximate the evolution of the whole system with an equation having typical form

$$\partial_t \phi = \nabla^2 \phi + f(\phi) + \eta(\phi) \tag{1}$$

where the diffusion term $\nabla^2\phi$ captures the spread of linguistic features from cell to cell, $f(\phi)$ captures the deterministic component of community dynamics within cells, and $\eta(\phi)$ is a stochastic term capturing innovation and random elements of network rewiring. J.B.'s "linguistic Ginzburg Landau equation" [5] is a deterministic example of such a model. When long range connectivity exists, equation (1) must either be augmented with a spatial integral term capturing long range connectivity, or it may be more appropriate to modify the coarse graining procedure to generate a new network model based on the pattern of human settlement. Coarse graining simplifies the mathematical form of stochastic terms, and because macroscopic dynamics involves a very large number of agents, predictability may start to emerge, potentially revealing new explanations for observed linguistic or cultural history. In summary:

Can coarse graining be used to classify microscopic models of language change according to their macrosopic predictions, revealing the large scale structure of the interaction network and predictability in linguistic and cultural change?

A particularly simple subclass of models of the form (1) describe *Neutral Evolution*, where there is no *conformity* by agents to locally dominant forms. Such models lack surface tension at interfaces, but can still produce spatial variation in linguistic and cultural traits driven by the stochastic term. A wide variety of spatial datasets exist (see e.g. [17, 21] for examples) which will allow us to explore if and when the presence of surface tension is required to explain observations.

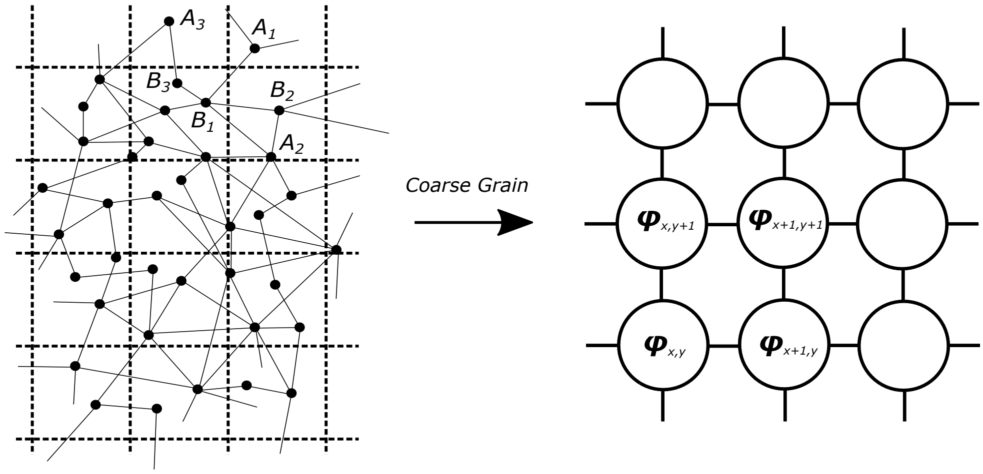

Figure 3: Coarse graining an agent based model on an embedded network. Here we have allowed two classes of speaker: A and B, labelling their linguistic states $A_1, A_2, \dots$ e.t.c. The network is divided into cells and the average state in each cell defines a state vector ϕ_{xy} where (x, y) is the geographical coordinate of the centre of the cell.

3 Evolving network structure and spatial dimensionality

Over the course of history, and especially in the Late Modern period, the network of linguistic and cultural links between individuals changes because people more frequently relocate, travel further, and maintain long-distance social contacts. A notable effect is the disappearance of isoglosses: in dialectological terms, *levelling*. We hypothesize that this occurs because the social network loses its quasi two dimensional structure and interfaces can only be linear in a two dimensional space. We suggest, though, that interfaces may still exist, but in a different form. Supposing that there is a space of dimension greater than two, into which we can place the nodes of the social network so that Euclidean and network distance *are* good proxies for one another (using, for example, multidimensional scaling). Suppose that this new space is three dimensional and contains a group of speakers who are geographically dispersed in real space but closely connected in the social network. In the new space they would form a cluster of nearby points, and if they shared some unique linguistic form, the "isogloss" for this form would be the surface of the cluster. In linguistics such patterns are referred to as *sociolects* and are visible as ordered differences in rates of usage of different variants by speakers of different ethnicities or socioeconomic classes [12]. Linguistic scholarship has investigated such group differences and their role in diachronic change, but models them as a different class of phenomenon from spatial evolution. However, since geographical and social closeness mean the same thing in this newly proposed model, a higher dimensional form of equation (1) still applies and we would expect surfaces to evolve by surface tension. We suggest that this is an exciting new way to generalise surface tension to embedded networks. To obtain a traditional map we project nodes back into two dimensions, turning our new interfaces into more exotic two dimensional structures. An alternative approach (if required) is to explicitly model the changing network structure, progressively introducing longer range links and observing the effects on the spatial distributions of variables. We have in linguistics a wealth of observational data which show the breakdown of traditional spatial linguistic boundaries, and this can be used to calibrate and test such models. In summary:

Can we use historical data to understand the changing structure of interaction networks, and can we understand the resulting changes in the distribution of linguistic and cultural variables using spatial models? Do interfaces still exist, but in a higher dimensional space?

4 Sources of data

Some of our predictions can be tested on synchronic data (data from a single point in time); for these, we will use data from linguistic atlases showing the distribution of features in a variety of languages situated in a variety of human and physical geographies. However, many of our questions focus on the dynamics of language change and so must be tested on diachronic data. For these, we have identified a number of key sources. Firstly, T.B.'s work on the history of Norwegian provides a number of large datasets distributed in space and time showing language change in the medieval period [3]. Complementing this, we will use the independently datable and localisable texts from the linguistic atlases of medieval English to map processes of change in a similar period but different geography

[13, 2]. Secondly, and crucially for the purposes of examining the role of network structure and the mechanisms behind levelling, we will examine data from the modern period. No single dataset distributed in space and time exists for this period, but in recent years a number of large restudies have been undertaken, and by treating these together with data from original studies we can create diachronic datasets. Thus we will compare late 19th century [7] to mid 20th century [19] to early 21st century [16] surveys of English English, late 19th century [22] to mid 20th century [6] to early 21st century [8, 14] surveys of German German, mid 20th century [9] to early 21st century [15] surveys of Swiss German and mid 20th century [11, 1, 20] surveys of American English to early 21st century data collected by B.V.

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