Spatio-Temporal Evolution of Language

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Language Grammars

- Grammar is the computational system of language, specifying rules for building sentences from words
- How do we learn grammars? There is a “paradox of language acquisition” due to “poverty of input”
- A “Universal Grammar” may be pre-wired into our brains, reducing the search space

Modelling the Evolutionary Dynamics of Grammar Acquisition

- We assume each individual has a certain ‘fitness’ determined by their grammar
- The dynamics can be described as ODEs

$$\dot{x}_j = \sum_i f_i x_i Q_{ij} - \phi x_j, \quad 1 \leqslant j \leqslant n$$

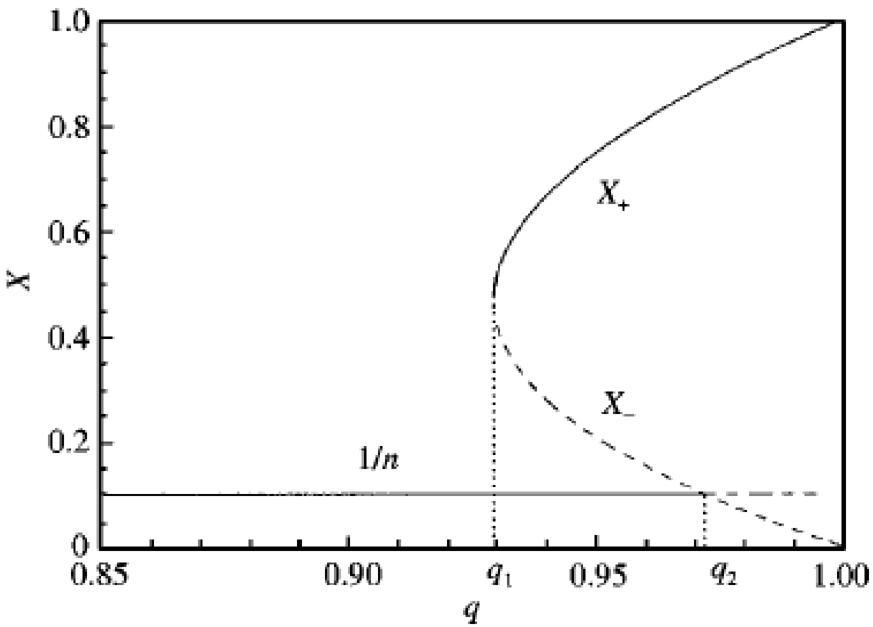
$$f_i = f_0 + \frac{1}{2} \sum_{j=1}^{n} (a_{ij} + a_{ji}) x_j.$$

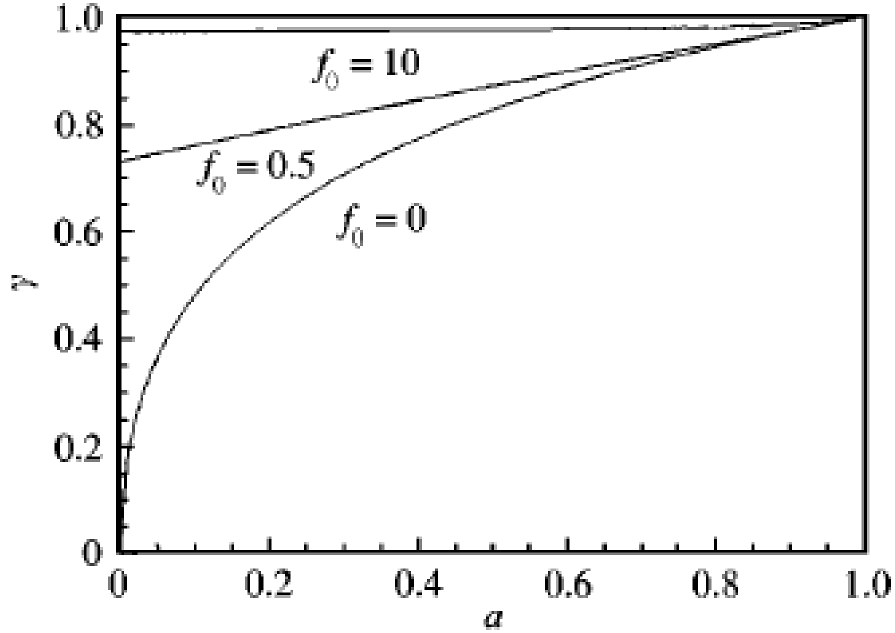
$$\phi = \sum_{m=1}^{n} f_m x_m$$

- Here x_i is the fraction of people using grammar i, f_i is their fitness, A is a ‘similarity’ matrix and Q a ‘transition’ matrix

Symmetric system: steady states

- Fitness becomes: $f_i = (1-a)x_i + a + f_0.$
- Define Q by $Q_{ii} = q, \quad Q_{ij} = u = (1-q)/(n-1), \quad i \neq j.$
- Here q is the 'learning accuracy'





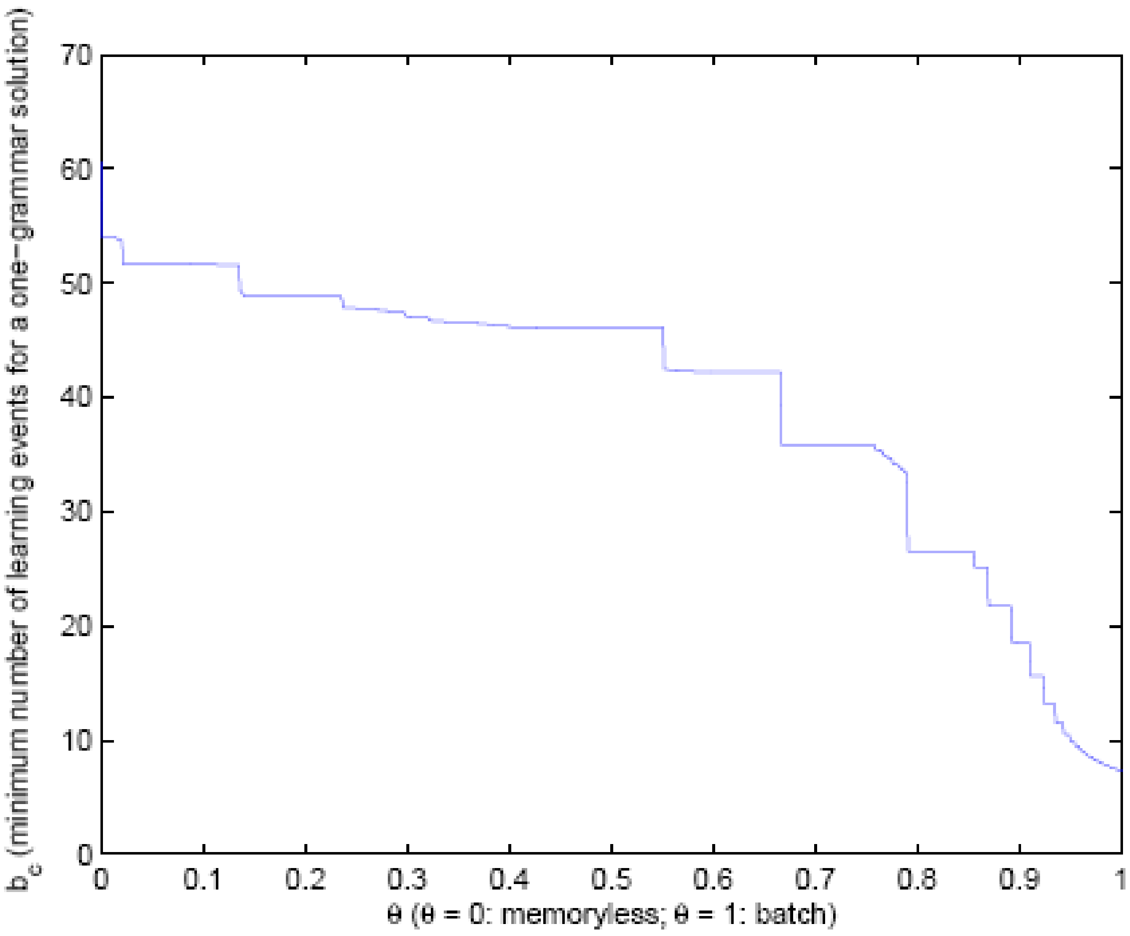
- For high values of q, we get essentially a one-grammar solution

Setting q: Learning algorithms

- Memoryless learning: start with a random grammar (out of n), update after each of b sentences if required
- Batch learning: Process b sentences all at once to choose a consistent grammar
- Hybrid (finite memory) case: intermediate of the two, set q to a linear combination (θ=0: memoryless; θ=1: infinite memory)

$$q = (1-\theta)\left[1-\left(1-\frac{1-a}{n-1}\right)^b \frac{n-1}{n}\right] + \theta\left[\frac{1-(1-a^b)^n}{a^b n}\right]$$

Effect of θ on learning efficiency



Adding spatial variation

- We would like to allow for language variation over space as well as time
- Our x_i variables become functions of both
- Fitness also varies spatially for speakers of any given language: we would like to compute it based on a weighted average of the grammatical profile in the neighbourhood
- This suggests using the second derivative

Modelling 1-D spatial variation

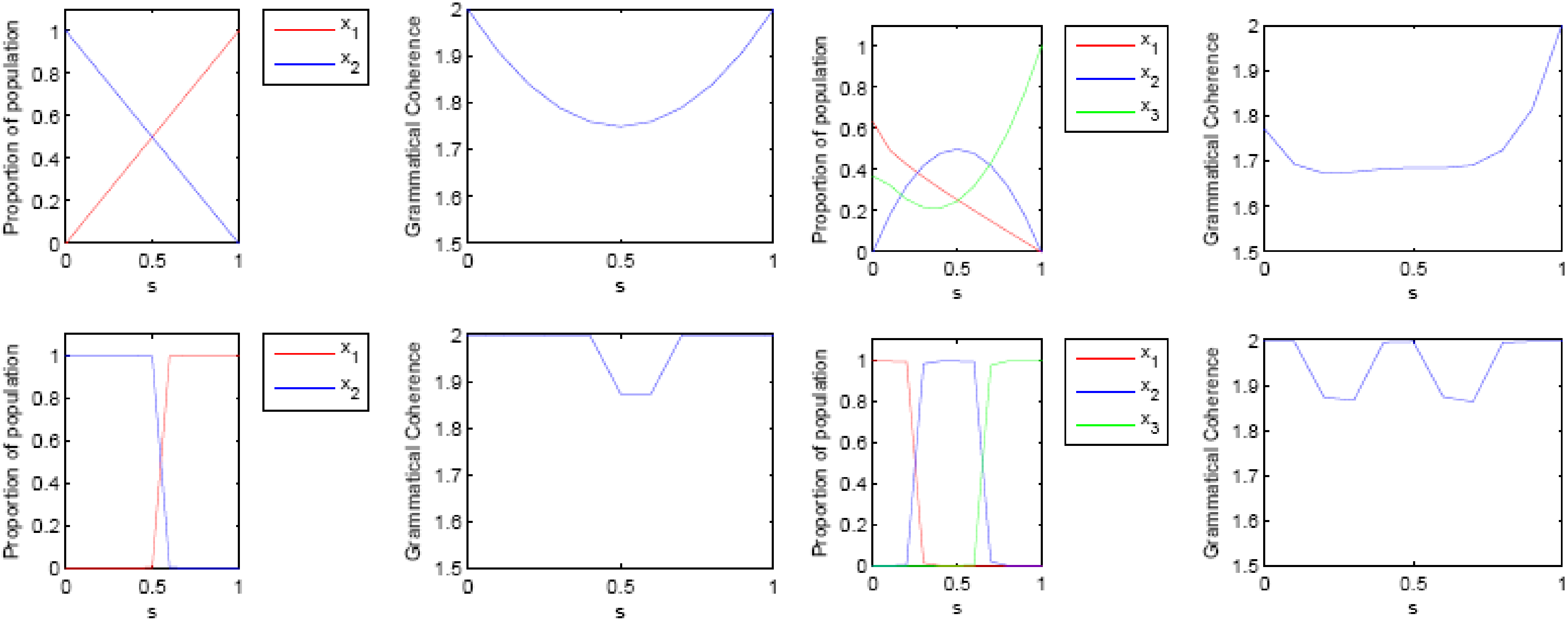
- We define fitness as follows now:

$$f_i(s,t) = f_0 + a + (1-a)\left(x_i + D\frac{\partial^2 x_i}{\partial s^2}\right)$$

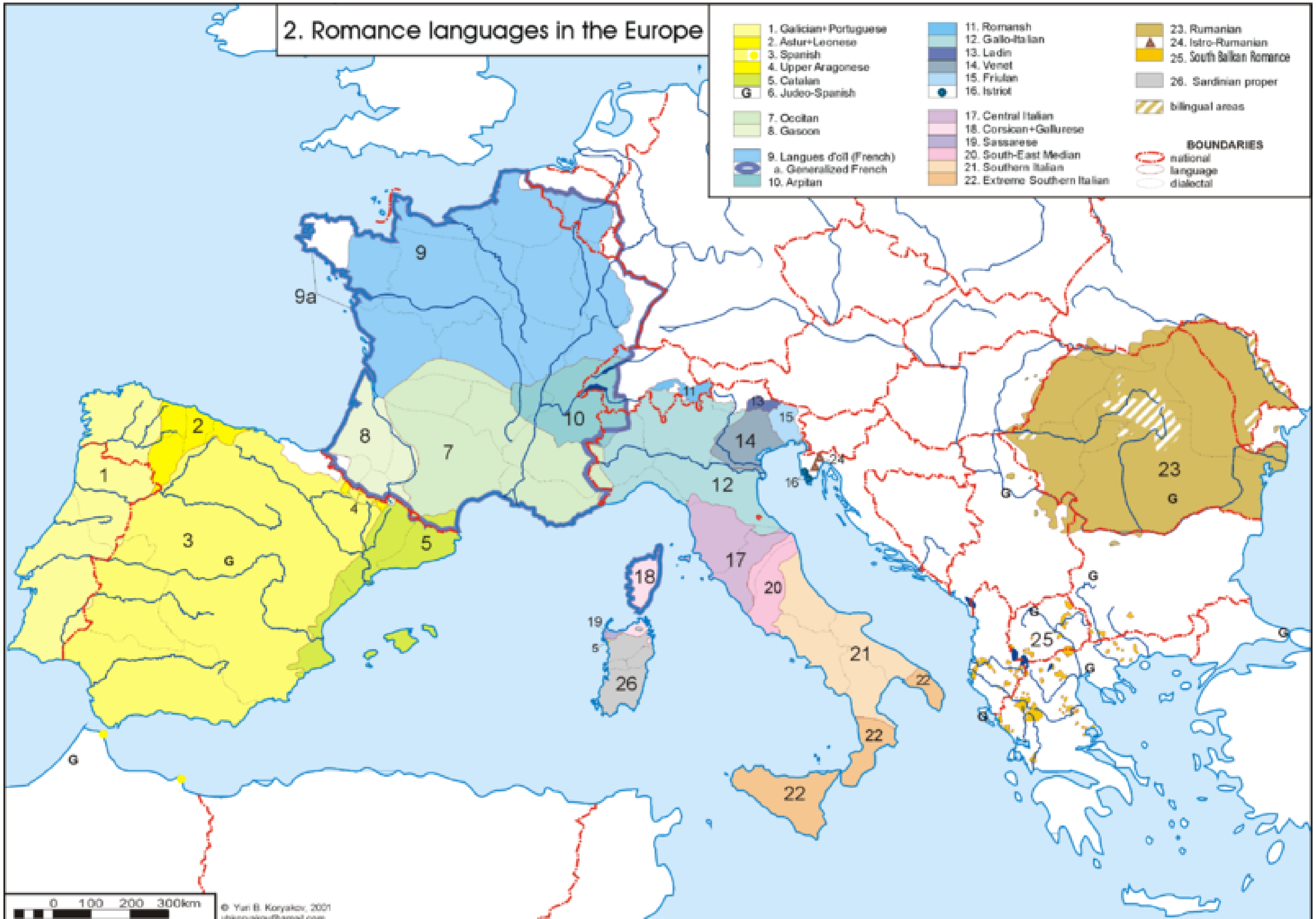
- The second derivative is positive if the neighbourhood value is higher and negative if lower: the last term gives some weight to this variation
- This is plugged into the original ODE system and it is integrated over time and space

Results

- We observe that regional one-grammar solutions emerge, with fairly sharp boundaries between regions



Real-world analogue



Further Work

- Extremely simple model: only looks at 1-D variation in space, does not account for spatial heterogeneity
- Evolution of languages themselves should go along with population dynamics
- More knowledge needed on mechanisms of human language acquisition in order to set parameter values appropriately

References

- Natalia L. Komarova, Partha Niyogi and Martin A. Nowak. The Evolutionary Dynamics of Grammar Acquisition. Journal of Theoretical Biology 209(1): 43-59 (2001). [This is the publication on the basic model]
- http://web.iitd.ac.in/~sumeet/EvolDynamics.pdf [This describes the extension with spatial variation]