Nettle, D. and Dunbar, R. I. M. (1997) Social Markers and the Evolution of Reciprocal Exchange, *Current Anthropology,* **38,** pp. 93-99.
Steels, L. and Kaplan, F. (1998) Stochasticity as a Source of Innovation in Language Games. In *Artificial Life VI* (Eds, Adami, C., Belew, R. K., Kitano, H. and Taylor, C. E.) MIT Press, UCLA, pp. 368-376.

For our experiments we implement a model featuring agents which learn as described in (de Boer, 2000). The only significant difference is the addition of spatial constraints on to the interactions between agents. 100 agents are arranged in a line, and teacher-learner pairs of agents are selected such that they are within ten units of distance of each other, with uniform probability. This is similar to the population model of (Livingstone and Fyfe, 1999), but without the preference for closer neighbours.

To aid interpretation of results, the population is split into neighbouring groups when viewing the resultant phonological systems. By contrasting the differences which exist within groups and between neighbouring and distant groups a view of the emergent diversity can be gained. As in our previous work, there is significant diversity across the population, with lower diversity inside localised subgroups. A continuum of gradual change is also apparent, with some minor discontinuities.

Discussion

We have repeated some of our previous work using a similar population model, but a different design and implementation of individual agents, and found broadly similar results. Further work exists in repeating some of Nettle's experiments, using similar population models but with learning based on multiple interactions between individuals. This we intend to do using de Boer's vowel learning agents, and hope to find results in accordance with those presented here and previously.

As the current debate on the necessity of social function settles, further avenues of possible research open. Not least a re-examination of the role of social status on linguistic evolution under varying social conditions. Having worked to show how social status is not required for linguistic diversity, it will again be time to investigate the effect it has on linguistic evolution.

References

de Boer, B. (2000) Emergence of sound systems through self-organisation. In *The Emergence of Language* (Eds, Hurford, J. R., Studdert-Kennedy, M. and Knight, C.) Cambridge University Press.

Lass, R. (1997) *Historical Linguistics and Language Change*, Cambridge University Press, Cambridge, UK.

Latané, B. (1981) The psychology of social impact, *American Psychologist*, **36,** pp. 343-365.

Livingstone, D. (2000) A modified-neutral theory for the evolution of linguistic diversity. In *The 3rd International Conference on the Evolution of Language*, 3rd-6th April, Paris.

Livingstone, D. and Fyfe, C. (1998) A Computational Model of Language-Physiology Coevolution. In *The 2nd International Conference on the Evolution of Language,* 6th-9th April, London.

Livingstone, D. and Fyfe, C. (1999) Dialect in Learned Communication. In *AISB '99 Symposium on Imitation in Animals and Artifacts* (Eds, Dautenhahn, K. and Nehaniv, C.) The Society for the Study of Artificial Intelligence and Simulation of Behaviour, Edinburgh, pp. 139-146.

Milroy, J. (1993) On the social origins of language change. In *Historical Linguistics: Problems and Perspectives* (Ed, Jones, C.) Longman, London, New York.

Nettle, D. (1999a) *Linguistic Diversity,* Oxford University Press.

Nettle, D. (1999b) Using social impact theory to simulate language change, *Lingua,* **108,** pp. 95-117.

otherwise even very small amounts of inter-group contact will destroy linguistic diversity across the agent population. We have previously criticised aspects of this model and its attendant explanation, principally on the grounds of the explicit averaging of existing phonological forms which is used in the learning algorithm of new agents (Livingstone, 2000).

A third model (Nettle, 1999b) based on Social Impact Theory (Latané, 1981) studies the effect of what Nettle terms the *threshold problem*. As the problem is stated, learners of a language will tend to learn the most common forms in use around them. Novel or uncommon linguistic forms will not be learned, and this acts to suppress linguistic diversity. The threshold problem cannot be overcome without social influence having a strong and necessary role – where an uncommon form is used by a speaker of high status it may be adopted by others, and this provides a mechanism for change and the spread of diversity. Where in the previous model the learned forms were found by an average of the current forms, here they are determined by a weighted-majority decision. For each of two competing forms a value is calculated based on the number of agents currently using the form and their distance from the learner – the higher value determining which form is learnt. This weighted majority choice reduces diversity within the model, and only an additional arbitrary weighting – ascribed to social status – can reintroduce variation.

Language learners do not, however, learn by taking large samples and choosing the most popular forms. Nor is competition between discrete and separate forms necessarily settled by the selection of one or other where it may be possible to learn both. These simplifications combined with the majority-rule learning algorithm favour Nettle's findings.

Another work, one which uses computational models to investigate language change rather than diversity, is presented by Steels and Kaplan, (1998). They find that stoachastic processes which exist in language use and learning may be sufficient for continued language change and innovation. Stochastic effects are considerably attenuated in Nettle's work due to the averaging and majority based learning algorithms, but succeed here in producing successful yet ever changing communication systems.

As a consequence, we argue that the results of Nettle's models are not conclusive, while acknowledging that they are illustrative of the impact that social status may have on linguistic change and diversity. (Our previous work concluded that social function or influence is not required for the evolution of linguistic diversity, but that such influences do affect the linguistic diversity and changes which occur.)

Diversity in Emergent Phonologies

Despite the criticisms placed against Nettle's work, the existence of different models supporting the same central argument provides a strength currently lacking in our own. To strengthen our own arguments now present some recent work on qualitatively replicating our results with a different model, one based on the work of Bart de Boer on emergent phonological systems.

In comparison with Nettle's phonological model (Nettle, 1999a) the model of de Boer has a number of advantages, although both models are restricted to vowel systems. While it is not intended as a model of how an individual acquires a phonological system, de Boer's is a successful model of how a shared phonology emerges in a linguistic community. As in the real world, the phonologies arise as a result of many interactions between individual speakers rather than through computed weighted averages of the current language of the adult population, as in Nettle. Further, the majority of the phonological systems which emerge in de Boer's model are also to be found in different human languages, evidence of how successfully the model captures the processes involved in phonological development.

Computational Models of Language Change and Diversity

Daniel Livingstone, University of Paisley
daniel.livingstone@paisley.ac.uk

Introduction

In recent linguistics literature on the sources and reasons for language change and diversity there are two principal opposing positions, divided over whether linguistic diversity is a result of 'purposeful' change (for examples, see Lass, 1997 and Milroy 1993).

It is a promising thought, at least to ALife researchers, that computational modelling might provide evidence to settle this debate. A number of computational models have been produced which investigate the problem. Unfortunately, the results of the models are as at-odds with one another as the original arguments they aim to resolve.

The authors' own previous work has supported the view, not that diversity is essentially without purpose, but that it is unavoidable and to be expected regardless of any purpose or use to which it may be put (Livingstone, 2000). Daniel Nettle has detailed a number of models with quite contradictory findings (Nettle and Dunbar, 1997, Nettle, 1999a, Nettle, 1999b), and a small number of other works exist on one or other side of the debate.

As a result, it is clear that a model alone will be unable to conclude the existing debate – rather, the models may be used as evidence with the arguments. One strength of Nettle's body of work is that the same result has been found from a number of different models. Finding some factor in the implementation of one model that would lead to unreasonable results does not affect the validity of the other results. Each model must be reviewed in turn, and alternative explanations proposed for why the results are as they are, or why the model is somehow inappropriate or how the results do not mean what Nettle claims they mean.

Further, Nettle's body of work has highlighted an inadequacy in our own. All of our work to date has been performed using the one basic model (as originally presented in Livingstone and Fyfe, 1998, and subsequently modified). For increased confidence in the evidence generated, it is important to obtain qualitatively similar results using different models.

The current presentation has two goals. First, to highlight weaknesses with each of Nettle's different models, whether of model design or implementation or of interpretation of results obtained. The second goal is to present recent results which support my own arguments from a significantly different model of the evolution of language diversity – one derived from de Boer's model of emergent phonology (de Boer, 2000).

Despite the contradictory results, we feel that computational models have much to offer for research into language change and diversity, and close by suggesting some directions for future work.

Nettle's Models of Linguistic Diversity

Nettle's first model (Nettle and Dunbar, 1997) is a demonstration of the adaptive benefits of social marking through linguistic diversity. Of Nettle's models, this is the easiest to reconcile with theories of adaptively neutral diversity. While an adaptive benefit has been shown for language diversity, it has not been proven by this work that such a benefit is *required* before language diversity can occur and the work presented we in (Livingstone and Fyfe, 1999, Livingstone, 2000) provides some evidence that such a benefit is not required.

A second model (Nettle, 1999a) studies how the phonological systems used by neighbouring communities affect one another, and the extent to which contact between groups limits the emergence of phonological diversity. Nettle concludes here that the selection of phonological forms must be strongly influenced by extra-linguistic social factors, as