**HENDERY — Geo-Language**

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**Geo-Language Games: An Agent-Based Model of the Role of Terrain in Language Diversity**

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One of the enduring questions in the field of linguistics is why some regions are linguistically diverse, while others remain or become relatively homogeneous. For example, New Guinea is home to 13% of the world’s languages, while having only 0.1% of the world’s population and 0.4% of the land area (Nettle and Romaine, 2000, 80). It has often been assumed that terrain plays a role in the different amounts of diversity in different regions, as near-impassable terrain means that population movement results in isolated groups without further contact, while flat terrain without significant obstacles or easily traversable bodies of water lead to continual long-term contact between different language groups (cf. Marck, 1986; 2000). In recent years the impact of terrain on the diversity of New Guinea languages has been overshadowed by research on other proposed factors, such as economic, social, cultural, and linguistic structural predictors (cf. Pawley, 2007; Currie and Mace, 2009; Lupyan and Dale, 2010; Greenhill, 2014). None of the existing research, however, fully accounts for the diversity question. With recent advances in the accessibility of mapping technology, 3D rendering, and satellite imagery, the time is ripe to consider terrain as a possible factor in language change models.

Agent-based modelling (ABM) represents a useful approach for considering the plausibility of terrain as one determinant of linguistic diversity. Agent-based models assume one or more computer-based autonomous, linguistic, reactive, proactive, and intentional agents who interact with each other and their environment (Wooldridge and Jennings, 1995; Gilbert and Troitzsch, 2005). Given an initial set of states distributed across a group of agents, and a finite set of rules, these interactions can then show interesting emergent patterns over time (Axelrod, 1997). As both Axelrod (1997) and Epstein (2008) argue, agent-based models can be useful as much for their explanatory as for their predictive value—as sorts of ‘thought experiments’ (Axelrod, 1997, 4) for elucidating how complex phenomena might emerge from simple assumptions. Increasingly, ABMs have been applied to social phenomena such as economic systems (Farmer and Foley, 2009), political cooperation and decision-making (Axelrod, 1997), urban development (Batty, 2007), social networks (Macy and Willer, 2002)—and language change (Steels, 1997).

However, agent-based modelling remains an underexplored—if tantalising—approach to understanding models of language change. As one example, Parkvall et al. (2013) proposed an agent-based model for the evolution of creoles in which agents follow extremely simple rules about talking to each other and updating their lexicon to ‘learn’ new words from each other during interactions. They tested this model for various combinations of founder languages, and found that it successfully predicts the lexifier language in the resulting creole.

The idea behind such a simulation is not to include *all* possible factors in language change but to pare them down to the minimum needed to get a realistic outcome. This shows us which elements are most important in language change. Elements that have been considered in previous agent-based simulation of language change include social networks (Troutman et al., 2008), genetic predisposition of the agents to language learning (Baronchelli et al., 2012), and diversity of founding population (Parkvall et al. 2013), but to our knowledge, no one has included geographical factors.

Here we present a model of language change in two sample regions: Palmerston Island (Cook Islands) and a range of terrain types in Papua New Guinea using a GIS-based agent-based model. In the first case the terrain is extremely flat, with no rivers or other potential obstacles to divide groups. The only terrain effects that could affect language change are the relative density of bushland that makes certain paths across the island easier to traverse than others. People are therefore more likely to encounter those who live near those paths than those who live in the denser bushland. In Papua New Guinea, on the other hand, we consider hilly terrain, rivers, and swampland as well as bush, so that population movement is much more constrained.

We argue relatively simple ABMs can represent complex emergent patterns typical of language differentiation among these relatively geographically proximate groups.

We build upon existing work with a web-based ABM framework, Fierce Planet (Magee, 2012; 2014). The affordance of this framework over more established ABM frameworks such as NetLogo, Repast, and CORMAS (e.g., Bajracharya and Duboz, 2013) is the relative accessibility of simulations; these can be easily deployed and shared with other researchers and communities. We adapt that framework for three-dimensional rendering using WebGL and Three.js, and import geographical models for both locations. For Papua New Guinea, we import DEM models developed by USGS. For Palmerston Island we construct a DEM model using World Machine since it is too small and low-lying to be picked up by satellite.

Both height and foliage act as cost-based constraints on the movement of members of different tribal groups. As a general rule, this constrains interactions between groups, while reinforcing bonding ties within groups. Our model shows that, given a common linguistic origin, over time geographical constraints act as a factor in the gradual divergence of dialect and language between two groups. This is especially so when one or both groups are exposed to exogenous influences. We also model a range of alternative scenarios, where connections between groups become easier or more difficult due to alterative pathways between them.

We make two contributions with our paper. First we demonstrate how linguistic diversity can be partially but plausibly explained by longitudinal accumulation of linguistic and other social interactions within versus between groups. We show that geographical influences can shape this accumulation. Second we show how complex geographic ABMs can be developed using current web standards. This facilitates broader engagement with the assumptions and algorithms of ABMs, and encourages critique and feedback from other researchers and the public.

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