Applications of Compl Adaptive Systems

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Applications of Complex Adaptive Systems

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Chapter VI

Unique Applications of Multi-Agent Models in Uncovering Language Learning Processes

Teresa Satterfield, University of Michigan, USA

Abstract

Multi-scale "artificial societies" are constructed to examine competing first- and second-language acquisition-based theories of creole language emergence. Socio-historical conditions and psycho-linguistic capacities are integrated into the model as agents (slaves and slave-owners) interact. Linguistic transmissions are tracked, and grammar constructions are charted. The study demonstrates how a complex adaptive system (CAS) approach offers clear indications for computational solutions to questions of language change and formation.

Introduction

How does a fully operational and accepted linguistic code evolve out of the cor ity of multiple languages and cultures in contact? What principles or mech make such language development possible, both at the individual (cognitive) the societal level? Various hypotheses offer explanations for how historical languages arose under precisely such "chaotic" language contact settings, n in plantation scenarios. Since creoles are not exactly the same as any of tl *language (L1)* source languages from which they emerge, creolists supp notion of creoles as adult manifestations of unsuccessful or "imperfect" eff *second language (L2)* acquisition. These "flawed" attempts are claimed to gra converge to a new code over the span of several generations of speakers (A 1995; Chaudenson, 1992, 1995; Mufwene, 1996; etc.). The *language biopr hypothesis* (Bickerton, 1981, 1984, 1988) is a competing account which su that plantation creoles arise within one generation, and only when young cl exposed to impoverished or otherwise deficient primary linguistic input "compe by creating a novel L1 from their immigrant parents' "defective" L2. A long- ing challenge for creole studies has been how to reliably test the two theori to obstacles such as imperfect records of speakers inhabiting historical pla communities, the extinction of early and intermediate linguistic forms, alon the added questions of creole studies' place within larger disciplinary contex as L1 and/or L2 language acquisition theories.

The general purpose of the current research is to shed light on underlying as tions of language acquisition theories and to serve as a "barometer" for s proposals concerning creole formation. We start from the premise that lar acquisition, with its complex sets of linguistic processes, as mediated by i and external factors extending across multiple timescales, can be fruitfully an as a CAS (e.g., Satterfield, 1999a,b, 2001, 2005a, 2005b, in press). For the of this work, a CAS is defined as a dynamical network whose emergent pro are produced bottom-up by the simple interactions of many individual elem CAS is complex in that it is diverse and made up of multiple interconnected it is adaptive in that it has the capability to evolve and to "learn" from exp within a changing environment (Bradbury, 2002; Holland, 1998). While th approach has been applied in several linguistic projects concerning human lar evolution (Bartlett & Kazakov, 2004; Briscoe, 2000, 2002; Culicover & Nowak Kirby, 1999; Steels, 1997), the present study takes model validity as a key (Burton & Obel, 1995); focusing on an application that, while a simplificatio system that it is designed to mimic, still adheres to reality. The intent is to p a principled explanation for real-world linguistic processes and componer basic level. Phenomena observed in real-world language acquisition fall na into the category of CAS, providing a window into linguistic development at

levels of analysis. At the local level, the present model considers how the existing *internal-language*, the grammar within the mind of each individual speaker, is represented. In turn, dynamical interactions of individuals generate collective linguistic representations at a global level, constructing a particular *external-language* as the linguistic convention of the community.

The CAS dynamics generated in the mapping between numerous external (socio-cultural) conditions of the plantation on one hand and the speakers' internal (cognitive) faculties on the other become quite complex because behaviors of the whole cannot be understood by simply observing the behavior of individual components. For example, the linguistic information inputted to a given inhabitant of the plantation depends on what other speakers are transmitting and receiving, how speakers process this input given their state of linguistic knowledge, how different speakers respond to different plantation conditions, and so forth. In short, the behaviors of inhabitants in the plantation **and** the linguistic code(s) that they ultimately adopt are "emergent" properties of interactions among **and** between speakers **and** the spatial layout of the plantation. Rather than using probabilistic techniques **and** purely statistical analysis, modeling the plantation's operations via agent-based computer models (ABMs) is a viable solution to the mapping problem (e.g., Epstein & Axtell, 1996; Ferber, 1998; Fox-Keller, 2002). Agents of the system are endowed with individual behaviors that must be taken into account, such that each agent is responsible for an activity or recognized property of a domain, yet there is no centralizing system coordinating the whole. Large-scale effects are produced in the domain as populations of agents interact and adapt locally in various ways and within a complex environment. Based on micro-specifications with regard to agents, the environment, and rules of behavior in the model, certain macro-structures and collective behaviors are generated in the system. ABMs enable the researcher to tease apart the contributions of each variable. Furthermore, unlike theoretical accounts that paint the "big picture" while glossing over crucial details, ABMs force us—due to the requirements imposed by programming algorithms—to make explicit the concept/process represented, and also the nature of the mechanisms involved in this process.

The objectives framing the current study are entirely practical. The primary goal is to replicate basic demographic and socio-cultural information in *"silico."* To this end, Sranan Tongo, an English-based creole originating in colonial Surinam is adopted as the base case for the ABM. Demographic parameters derive from historical archives on Sranan (Arends, 1992, 1995, 1996; Braun & Plag, 2003; Migge, 1998, 2000; Seuren, 2001; Van den Berg, 2000; Winford, 2000, 2001, 2003). Theory-based linguistic parameters are also encoded into the ABM, as discussed later on. After releasing an initial population of slave and slave owner agents into the environment, the model is examined at regular intervals. The next objective is to analyze any linguistic data generated, in order to determine whether the interaction between multiple agents indirectly results in the emergence of linguistic structures in the communicative context designed, and to determine if these emergent structures are

identifiable as creolized forms similar to those of Sranan. The interactions a in turn serve to explore in detail the L1 and L2 hypotheses related to pla creole formation.

The behavior of a CAS is not always predictable and the errors a model ge may not be a deterministic function of its parameter values. As the CAS or tion is emergent, the agents in the current study might end up with quite d linguistic repertoires than the historically documented human case, yet it is ext thought provoking to test whether the agents can arrive at the real-world solution, based precisely on the terms advanced under specific accounts of development. The current study therefore takes no position on whether an L2-acquisition theory of creole formation is the more plausible hypothesis gi data available. Rather, the preliminary stance is that no "natural" methodol detailed examination of the impact and contributions of either hypothesis previously. The present inquiry represents an effort to implement a metho that may by-pass some of the barriers which have hindered past creole for research.

The chapter proceeds as follows: after a brief overview of the topic, a desc of the ABM is outlined. The trajectories and outcomes of two experiments a presented. Subsequent discussion explores the likelihood for creoles to be based on the proposed configurations of demographic, social, and psycho-l tic variables as integrated into the model. Implications and suggestions for research conclude the chapter.

Background

Theoretical Overview

Linguistically speaking, a *creole* language emerges when speakers of m unintelligible languages must communicate with each other (Arends, Mu & Smith, 1995; Holm, 2000; Mühlhäusler, 1997; Sebba, 1997; Thomason 2001; Winford, 2003). In this context, vocabulary items of the dominant cu language (the *superstrate*) may be learned; however, the superstrate's gramma (completely) mastered. Grammatical features of word order, verbal paradigr the like may be retained from the *substrate* (supplanted or recessive) langu Frequently a new language comes into being, and in its earliest stages is kn a *jargon* or *pidgin*. *Pidginization* is a process involving (linguistic and func communicative) reduction. If a pidgin becomes accepted in the community usage stabilizes and diffuses the resultant language is known as a *creole*. In c to pidginization, *creolization* is a process of expansion generating a quite di

grammar than previously exhibited by speakers in that particular linguistic surrounding.

Many creolists consider impoverished L2 access to be the major catalyst for creole language development. Under this hypothesis it is proposed that, for example, newly arrived adult slaves from Africa after a time were not exposed to the original European superstrate of French or English, and so forth, but instead learned "approximations" of these L2 targets from already acculturated adult slaves and from other recently imported slaves (Chaudenson, 1995). The approximate versions of the superstrates are argued to be the foundations for creole language varieties used today. In contrast, creole language formation accounts based on the *language bioprogram hypothesis* (LBH) (Bickerton, 1984) place primary importance on young children's inherent predisposition to acquire any human language. The LBH posits the existence of a species-particular and universal biological "blueprint" for L1 acquisition. In chaotic language contact settings, such as institutional slavery, the child's language bioprogram is argued to give abrupt rise to a creole grammar. The LBH is also invoked to explain a range of linguistic properties that are considered to be common to all creole languages.

In the standard psycho-linguistic references, it is widely held that young children attain L1 and L2 competence implicitly and without conscious effort, whereas adults display varying degrees of "impairment" in L2 acquisition (by monolingual native speaker standards), even when possessing considerable motivation and resources. Lenneberg (1967) describes such age-related differences in terms of the *critical period hypothesis*, where a developmental window exists in the linguistic maturation of humans, such that between the age of 2 years and puberty, it is biologically possible to be exposed to primary linguistic input and to acquire any language in a native speaker capacity. Before and after this approximately 10-year period of opportunity, successful language acquisition is claimed to be increasingly more difficult. That a learner's capacities diminish or are not fully attainable over time is richly attested in studies of specific domains of linguistic knowledge (Johnson & Newport, 1989, 1991; Larsen-Freeman & Long, 1991; Miyake & Shah, 1999; Strozer, 1994; Weber-Fox & Neville, 1996; Werker & Desjardins; 1995). However, certain abstract properties of L2 appear to be successfully acquired by the adult learner, even in the absence of transfer of L1 knowledge to the developing L2 system or explicit L2 instruction. For instance, adult learners frequently master complex L2 word orders while simultaneously exhibiting flawed knowledge of L2 tense verb markers or plural noun markers (Lardiere, 1998a, 1998b, 2000; Lightbown, 1983). The totality of studies have led many investigators to claim that adult L2 acquisition differs significantly from both the initial and the end states of L1 acquisition, although the exact reasons for these differences are by no means obvious (Hudson & Newport, 1999; Hudson-Kam & Newport, 2005; Hyltenstam & Abrahamsson, 2003; Ionin & Wexler, 2002; Sorace, 2003) and creolist studies (DeGraff, 1999, 2005; Lumsden, 1999; and comments in Winford, 2003).

Base Case: Sranan Tongo

Due to its relatively well-documented history, Sranan Tongo is adopted as case for the ABM. Sranan originated from the language contact situation with Dutch, and French settlers utilizing African slave labor on small Suriname from 1600-1650. Roughly half of the European settlers in the community w ish. By 1665, approximately 3,000 African-born slaves labored in the regic with about 1,500 permanently installed European planters. A Dutch coup caused a mass exodus of the majority of English colonists from Surinam; l it is not clear whether the slaves acquired by the British remained in the More than 18,000 slaves were imported from 1680-1700, with similar imp rates occurring through the 19th century. The proportion of Africans to Euro Surinam rose from 2:1 in 1665 to 20:1 in 1744. Plantation numbers were r decimated from the slaves' short life expectancy, low birth rates, and escape. males were the preferred commodity of slave-traders (Kay, 1967), with ma outnumbering female slaves about 2:1. With such small numbers of femal population and the high mortality among slaves, the slave populace was s through the constant influx of new African labor, rather than from natural Precise information concerning European demographics, in particular non- offspring, is murky and is absent in most studies on creole formation.

Linguistically, modern Sranan Tongo exhibits several typological properti in other creoles: namely, highly impoverished verbal (inflectional) marke that the verb form is the same for all tenses, moods, and persons; marking mood, aspect, and negation expressed by pre-verbal particles, and fixed verb-object word order in declarative and interrogative constructions:

1. Mi no ben si en. *"I did not see him."*
2. Psa te unu kaba nanga skoro dan wi o meki pikin nanga den sani dati
   "Only when we finish with school, then we'll have kids and a things."
3. Ma yu nelde yu mama dati wi e go prei bal?
   "But have you told your mom that we're going to play basketball?"
4. Dan te mi miti en mi sa aksi en.
   "Then when I see him I will ask him." (Winford, 2001, p. 1)

Sranan Tongo's superstrate language is essentially Early Modern English. (1995) points to language families on the western African coast as forming S substrate. A primary substrate likely formed from early arrivals (1650-172 50% of imported slaves speaking languages of the Gbe-cluster (Fon, Ew

40% from Bantu languages (e.g., Kikongo). Slaves imported between1720-1740 spoke mainly Gbe and Kwa from the Nyo-branch. African languages most likely contributing to post-1740 Sranan are Fon (and other closely related Gbe-languages), Kikongo, and Twi (in the Kwa group). The substrate influences were subject to frequent fluctuations, depending on the quantity and regional origins of slaves in the population at any given time. The linguistic environment appears to gradually become more homogeneous within a 75- to 90-year period, reflecting the prominence of the post-1740 African languages (Arends, 1995).

Degrees of social distance existed early on in the plantation, putting into place restricted social networks between various groups. Over time the plantations functioned as increasingly hierarchical organizations (Price & Price, 1992). In 17th and 18th century Surinam, the possibility of gaining access to the linguistic variety with the highest prestige would have been distributed differentially, rather than as an L2 model equally available for all slaves. Social stratification likely occurred along the following boundaries in the plantation: European versus African; older versus younger; elite slaves, including overseers and house slaves, versus field hands; and to a lesser extent, slave elite with diminished manual tasks versus highly skilled African craftsmen (Valdman, 2000).

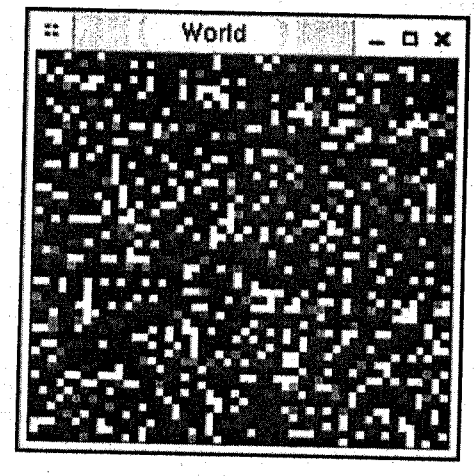
Model Architecture

Environmental Specifications

The model implements the generic software platform SWARM (Swarm Development Group 1999-2003). The main components of the framework are specifications for the environment and agents, and local rules for the environment and the agents. The environment consists of the physical landscape, or search space, as the spatial boundaries of the model. The space is made up of a 50x50 square lattice that holds 2,500 slots. Agents are color-coded squares representing five different African and European populations, shown in Figure 1.

Environmental parameters informing population make-up are projected from Surinam's historical statistics (Arends, 1995, 1996). As presented in Table 2, a 2,500-person carrying capacity is specified as the *population limit rule*. Per Geggus (1999), no live births occur during the first 12 iterations of the model, as denoted under *delay Years*. Other population parameters represent historical records of social affiliations, such as: *master-to-slave* ratio in the plantation society, *high-status slave (i.e., houseslaves)* ratio *to low-status slave (fieldslaves)* ratio, *male-to-female slave* ratio, *child-to-adult* ratio in the total society, and the *percentage of fertile adults* in the general population. All adult agents specified as [+ fertile] have the same

Figure 1. World (population of agents) as 50 x 50 square lattice holding 25(Agents are color-coded squares representing five different African and E populations (Color-coding in this and subsequent figures has been remc publication).



potential to "procreate" with adult interlocutors of the opposite sex. Reproc success is then subject to the *newborn survival rate*, which regulates the n of live births in the plantation.

Language variables encoded as part of the agent's internal (cognitive) "environ are summarized in Table 1. These parameters fall out from notions of the spe capacity for generating and analyzing linguistic structure, formally realize cognitive faculty for language (Chomsky, 1995, 2000, Chomsky et al., 2002 endoff, 1997, 2002; Sharwood-Smith & Truscott, 2005). European *eWordmor* and African *aWordmorpheme* parameters constitute ratios for word formati morphemic stems and affixes. These ratios supply the maximum number gramn affixes, such as verbal inflection or plural markers, permissible with a trans word stem. African languages are mapped three grammatical preverbal marl every one word stem (DeGraff, 2002, 2005; Fabb, 1992). European language two grammatical affixes per word stem, based on Early Modern English dat linguistic exchange with another agent, newly encountered items are first stc working memory (temporary memory buffer). (A linguistic exchange is defi the transmission and receipt of an "utterance [string of words]." All exchang agent-to-agent.) The *Morpheme Learning Rates* regulate the maximum num

Table 1. World parameters (environment profile). Model's parameterizable theoretical and demographic constructs used to describe system. Refer to text for detailed discussion.

WORLD PARAMETER	ACTION	VALUE
WORLD SIZE	dimension of landscape	50
NUMBER OF AGENTS	initial number of inhabitants	750
POPULATION LIMIT	carrying capacity of world	2500
DROP ALLOWED	agents "removed" in 1 time-step	75
E-NEWBORN SURVIVAL	rate of survival for Euro infants	0.75
A-NEWBORN SURVIVAL	rate of survival for Afro infants	0.30
SLAVE HIGH-LOW RATIO	proportion hi to lo status slaves	0.50
MASTER-SLAVE RATIO	proportion slave-owners to slaves	0.05
MALE-FEMALE RATIO	proportion slaves: men to women	0.50
CHILD-ADULT RATIO	proportion children to adults	0.30
DELAY YEARS	time elapsed before childbirth	1.0
FERTILE ADULT %	adults able to procreate	0.56
LEXICON SIZE	elements stored in creole lexicon	1000
E-WORD-MORPHEME RATIO	maximum Euro-affixes transmitted with Euro-wordstem	2.0
A-WORD-MORPHEME RATIO	maximum Afro-affixes transmitted with Afro-wordstem	3.33
E-MORPHEME LEARNING RATE	maximum Euro-affixes put in working memory in 1 exchange	2.0
A-MORPHEME LEARNING RATE	maximum Afro-affixes put in working memory in 1 exchange	2.0
NUMBER OF E-MORPHEMES	maximum available and learnable Euro-affixes	50
NUMBER OF A-MORPHEMES	maximum available and learnable Afro-affixes	100
E-WORDFLOW	maximum items in Euro-utterance	20
A-WORDFLOW	maximum items in Afro-utterance	20
DISTRIBUTION OF AFRO LANGUAGES: RATIO 1	substrate language #1	0.50
DISTRIBUTION OF AFRO LANGUAGES: RATIO 2	substrate language #2	0.30
DISTRIBUTION OF AFRO LANGUAGES: RATIO 3	substrate language #3	0.15
DISTRIBUTION OF AFRO LANGUAGES: RATIO 4	substrate language #4	0.05
LENGTH OF A YEAR	time-steps = chronological year	12
NUMBER OF SLAVE INDICES	'tag' based on slave ethnic, linguistic, occupational features	3 digits: X-Y-Z

African or European grammatical markers deposited in working memory any given exchange, whereas the *number of Morphemes* provides the upper on the array of respective European and African grammatical markers availa learnable. The *lexiconSize* specifies the size of new word stems and affixes in the lexicon (long-term memory). On analogy with the resources posite language processing literature, the agents in the model store informatior lexicon only after a specific number of linguistic exchanges, when an item h encountered repeatedly. *WordFlow* represents the maximum number of forr tained in an utterance in European (*eWordFlow*) or African (*aWordFlow*) lan according to the word order typology of each language. A string between 1 items (stems and affixes) is randomly generated in the current ABM, based agent's linguistic and social background. Due to space considerations, out *Wordflow* utterances will not be presented. These items are subsequently tr ted as an output string to other speakers during a linguistic exchange. The re of the utterance acquires information (i.e., analyzes as an input string whos may, over time, be stored in the lexicon).

Chronology is included as a feature of the ABM. For each cycle of language i tion, one unit of time elapses. The hypothetical *Length of a Year* parameter 12 iterations in the current program. While these time steps are abstractior

Figure 2. Population distribution over time based on documented stages in Su Graph lines, from bottom to top: European population, Child population, population and Total plantation population (labels in original color-coded in this and subsequent figures are ordered differently than actual graph lin

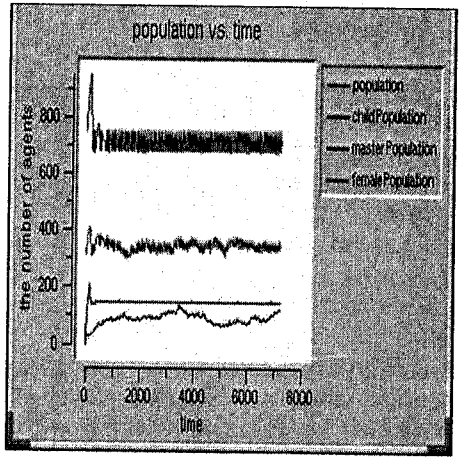
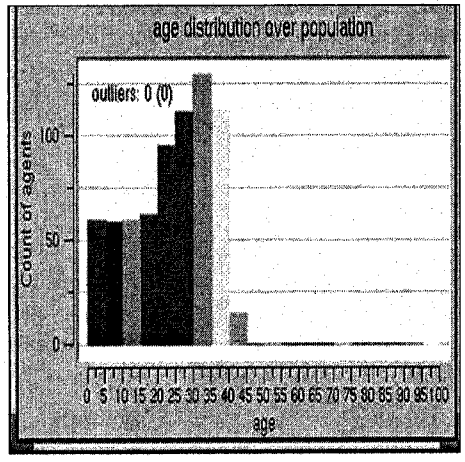


Figure 3. Age distribution at cycle 7000 in the model, based on historical demographic data of Surinam described by Arends (1995).



play an important role in identifying historical language contact benchmarks over a specified period. Likewise, Figure 2 illustrates population distribution over time, following the historical demographic range presented previously, as implemented in the model. Periodic oscillations correspond to historically recorded stages of decreased fertility and low birthrates followed by mass slave importation in Surinam. Figure 3 represents age distribution, as documented in real-world Surinam plantation societies (Arends, 1995).

Specifications of Agents

Agents are assumed to be social actors who have individual features, behavioral rules, linguistic knowledge, and language learning resources, as highlighted in Table 2. Fixed attributes based on gender, racial group, age of death, and so forth are designated for each agent as unique profiles. Each profile contributes to the demographic makeup of the plantation. Many states are encoded in binary (0,1) alphabet, based on specifications such as *sex*, where 0=male, 1=female; *dead* 0=no, 1=yes; *social class*, where 0=non-slave, 1=slave; *fertile*, where 0=no, 1=yes; etc.). Cultural identity and social status are flexible parameters varying over time, per historical statistics presented for Sranan. Slave agents are further monitored via

Table 2. Agent Profile parameters of individual features, linguistic knowledge language learning resources. Attributes based on gender, racial group, age of d parents, etc., are designated for each agent. Many states are encoded in bi alphabet. Refer to text for further discussion of parameters.

AGENT PARAMETER	ACTION	VALUE
ID	agent identification number	#1018
SEX	gender: 0=male, 1=female	0
SOCIAL CLASS	social status: 0=non-slave, 1=slave	1
AGE	"years of life":12 time-steps = 1 year	3.0
FERTILE	reproductive capability: 0=no, 1=yes	0
DEAD	mortality: 0=no, 1= yes	0
SLAVE INDEX	3 digit tag of ethno + linguistic background + occupation index	1-0-0
X	Agent #1018 location on X-axis	33
Y	Agent #1018 location on Y-axis	4
EURO LEXICON SIZE	items stored as European lexicon	0
AFRO LEXICON SIZE	items stored as African lexicon	0
EURO WORDFLOW	maximum items in Euro-utterance by Agent	20
AFRO WORDFLOW	maximum items in Afro-utterance by Agent	20
MOM CLASS	social status: Agent's mother	0
DAD CLASS	social status: Agent's father	1
MOM INDEX	occupation index: Agent's mother	0
DAD INDEX	occupation index: Agent's father	2
MOM EURO WORDFLOW	maximum items in Euro-utterance by Agent's mother, directed to Agent	0
MOM AFRO WORDFLOW	maximum items in Afro-utterance by Agent's mother, directed to Agent	0
DAD EURO WORDFLOW	maximum items in Euro-utterance by Agent's father, directed to Agent	6
DAD AFRO WORDFLOW	maximum items in Afro-utterance by Agent's father, directed to Agent	6

the *slaveIndex*, ethnolinguistic and social information in the form of a 3-digit "tag" similar to Axelrod's (1997) cultural chromosome. Adult slaves are assigned a status marker as part of the slave index based on their occupational roles in the plantation society. Overseers (index =1) have high occupational status among slaves, whereas house-slaves have an index of 2. Field hands and infirm slaves receive progressively lower indices. Slave-owners are categorized by 0.

Specification of Movement Rules

Movement functions provide the basis for language contact in the plantation. Agents are located in a specific slot, identifiable by ordered pairs of x-y coordinates. Inhabitants never overlap or occupy the same position in the community. Agents seek interlocutors, and thus indirectly "compete" to move through the search space, with agents of higher status having priority for movement over lower status agents. The fact that children receive the second highest movement preference is based on historical accounts (e.g., Blassingame, 1972, p. 96; Ochs, 1996) that (slave) children were typically not as confined as the adult slaves, and until about age 10 were freer to roam about the plantation setting. Movement is executed when an agent moves to the closest unoccupied cell that also has neighboring agents. The current model allows for a maximum of four surrounding neighbors at the north, south, east, and west slots, following the formal conception of Von Neumann neighborhoods. Access is restricted to receiving linguistic information from higher status neighbors, so while an agent can potentially participate in exchanges with four neighbors in a given learning cycle, she may conceivably be limited to one exchange if no other neighbors are "acceptable" in that particular learning cycle.

Specification of Agent-Interaction Rules

Linguistic exchange allows for processing and acquisition of the input languages to which agents are exposed, contingent on individual cognitive resources and social factors. Due to the range of possible linguistic encounters, the agent may form novel linguistic patterns that he/she subsequently transmits to others; alternatively, he/she may transmit their existing L1 or L2 structures. The adaptive nature of the CAS is such that neither the selections made by the agents, nor the overall results are necessarily predictable: the agent's internal-language can undergo drastic changes based on the outcomes of random exchanges. An individual's grammar may eventually be adopted as the external-language of the collective population through multiple, autonomous interactions of individual agents.

Experimental System

Hypothesis

The experimental parameters that make up this particular ABM can be manip in many ways; however, the specific purpose of this inquiry is to test two proposals of creole formation, adhering closely to the criteria advanced respective L1 and L2 theories. Regardless of the theory implemented, if a grammar emerges in either case, it is predicted to exhibit structures simpli termed *"prototypical creole effects,"* as observed in modern Sranan. Such prc observable as the output of the ABM should minimally include: subject-verb word order, a largely European (English) *superstrate* vocabulary, and Afric guage *substrates* in the form of (limited) inflectional particles and markers.

Experiment I: "Imperfect L2 Hypothesis"

Background

Standard creolist references portray L2 acquisition along a continuum in creole grammar constitutes "imperfect" L2 learning, as it is considered t come of adult L2 acquisition under unusual social circumstances, producing L2 grammar over the span of several generations (e.g., Chaudenson, 1995; 2000; Singler, 1996; Thomason & Kaufman, 1988). Shortcomings in L2 atta are attributed directly to the quality, quantity, and context of linguistic dat able to the learner; and indirectly to the cognitive resources of the adult la learner himself/herself. Due to the non-normative living conditions under many creoles surface, child populations are assumed peripheral to creole de ment, even to the degree that they would presumably interact with and affe L2 acquisition. Arends (1995, p. 268), among others, calculates that the pr of children was statistically inconsequential (consistently less than 20%) i Surinam. Consequently, child language is claimed to have no enduring str effect on emerging creoles such as Sranan, at best contributing only in the subs regularization of a formed creole grammar (Winford, 2003, p. 356).

Method

To explore the L2 hypothesis, the basic context of "imperfect" adult L2 acqui reconstructed. Monolingual adults exclusively make up the community of la learners, with child language learners (11 years and younger) absent from this

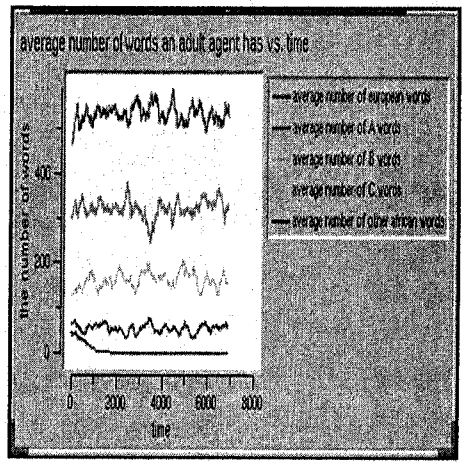
scenario. A rigid social hierarchy simultaneously constrains African slaves' access to Europeans and to the actual superstrate targets. Adult (age-related) L2 acquisition capabilities such as limited acquisition of L2 inflectional markers are encoded as general specifications, while the population control mechanism extinguishes the possible appearance of locally born children. Population size is stabilized via regular influxes of adult African slaves, randomly appearing every 240-300 time-step intervals, on analogy with historical occurrences. The model's demographic and environmental properties are initialized. Adults receive their specific agent profiles and are distributed into the artificial society. Contacts occur through the movement rule. Regardless of closeness of proximity, the neighbors must be "socially eligible" for linguistic exchange: higher status agents transmit to those of lower status. The following learning algorithm is implemented: agent A transmits an initial utterance to her adult neighbor, agent B. If an item in agent A's utterance is not found in the current lexicon of neighbor agent B, B will then add the new element to her working memory, contingent on the social and linguistic constraints outlined. If agent B receives an utterance from adult agent C and encounters the new word again, agent B will add this new item to her lexicon (long-term memory). Thus, a critical assumption is that statistical frequency plays a role in the language learning process (Hudson-Kam & Newport, 2005; Saffran, Aslin, & Newport, 1996). The initial cycle ends and the algorithm can be repeated for any number of iterations. The outcome of this experiment is based on agent activity spanning 7,000 iterations.

Results

Figures 4 and 5 represent the local level, the internal-language of an average adult inhabitant in the population, where the average speaker is statistically an adult male field slave. "Screenshots" of the average lexicon along any given point in the experiment are shown. Figure 4 illustrates the composite of European- and African-language words across time. (Fon is represented in the key on the right-hand side of the graph as *"average number of A-words"* to denote its high demographic status among African-languages. Words/stems from Kikongo are represented as *"average number of B-words."* The *"average number of C-words,"* represents Twi. The category *"other African-words"* is representative of minority African languages.) After the initial 1-2 generations, the average adult speaker possesses a small amount of L2 vocabulary. This state is represented nearly exclusively by African languages, with little influence from European elements. The average number of European words steadily declines from approximately 50 words/stems in an average lifetime (e.g., t_0 to t_{500} iterations).

Figure 5 highlights the average adult's store of inflectional (grammatical) markers. The top-most line signals the inventory of African-languages markers/particles, shown initially to be slightly less than 100 items across all African languages.

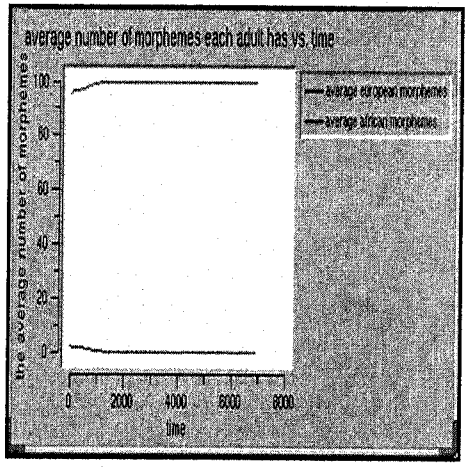
Figure 4. European- and African-language words in average adult's lexico time. Fon (top line) is "average number of A-words" to denote its high demo status among African-languages. Words/stems from Kikongo (second line fi are "average number of B-words". "Average number of C-words," repres (third line from top). Category 'other African-words' (second line from represents minority African languages. Number of European words (bott declines over time in average adult lexicon.



There is evidence that the adult can acquire inflectional information since o 500-1,000 cycles, the knowledge of African-based markers reaches its ma indicating adult L2 acquisition of inflectional affixes. This value remains co 100 markers. In the same time span, the number of European (English) infl affixes in the internal-language decreases to zero.

Figures 6 and 7 represent external-language within the adult "imperfect L2" demonstrating structures acquired across the general population. These gra reflect the input to which L2 adults in the environment would be potentially at any given time. Figure 6 shows the quantities of vocabulary acquired ac total population. In the initial time steps, Fon items are acquired with the frequency across the community. The global rate is reported at 250-35 learned per cycle in this experiment, as compared to the average individual ir (Figure 4) with 400-500 L2 items in Fon. The collective L2 lexicon emergi

Figure 5. Average adult's store of inflectional markers. Topmost line signals L2 inventory of African-languages markers, shown initially to be slightly less than 100 items across all African languages. Adult acquires inflectional information for 500-1000 cycles, when knowledge of African-based markers reaches its maximum. Number of European (English) L2 inflectional affixes acquired (lower line) decreases to zero for average adult.



community is smaller, yet all languages in the contact setting initially contribute. After 500 time steps, Fon and Kikongo words/stems are learned at nearly equivalent rates by the general population. At t_{1000}, the frequency of Fon words acquired shows minimal gains, then drops substantially while Kikongo remains stable across all speakers. Fon eventually regains dominance (likely owing to the periodical influx of slaves). European words/stems emerge early within the population, but disappear beginning in cycle 1,500.

Figure 7 charts the population-wide acquisition of English and African language inflection over time. Two lines are actually superimposed, yet appear in the graph as a single "flat" line given their equivalent values. The non-activity of this graph indicates that L2 acquisition of African or European (English) inflectional items into the external-language of the general plantation does not occur, even while certain individual adults may acquire L2 inflection, as demonstrated in Figure 5. A similar pattern has been documented in real world pidgin languages. We will return to further discussion of these points shortly.

Figure 6. Vocabulary items acquired across total adult population. In initi steps, Fon items (A-words and top range of graph) are acquired with high quency. Collective L2 lexicon emerging is small, yet all languages in contact initially contribute. European words/stems (bottom left corner of graph only) e early within adult-only population, but disappear beginning in cycle 1500.

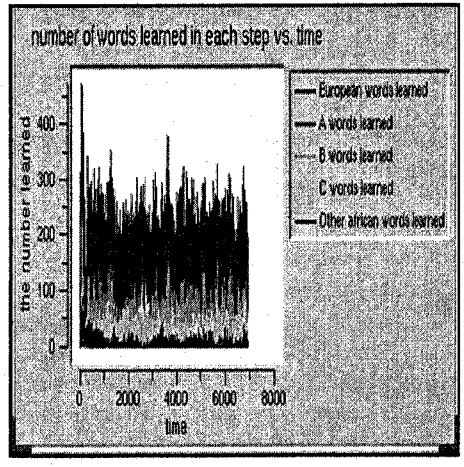
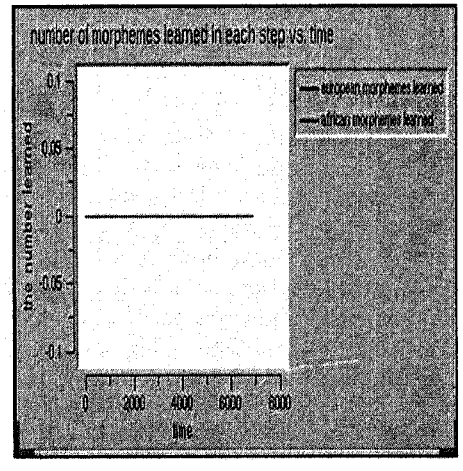


Figure 7. Number of English and African language inflectional morphemes ac by the total adult population over time. Both lines are at 0, indicating that whil morphemes may be acquired by certain individuals (as shown in Figure 5, are no African or European (English) inflectional items that are learned t L2 acquisition processes by the entire adult population of the plantation.



Experiment II: "Language Bioprogram Hypothesis"

Background

The LBH advanced by Bickerton (1984) and others operates under the premise that young children within the "Critical Period" are the sole creators of creoles, and as a result, creoles are formed abruptly within one generation of L1 speakers. The idea is that child populations create a novel L1 system when exposed to chaotic or degenerate primary linguistic input. Evidence for the LBH is based in large measure on synchronic L1 studies of child language and multi-language contact in early 20th century Hawaiian plantations.

Method

The LBH constitutes a scenario of both children (age 11 years and younger) and adults. The first population of children appears only after 12 time steps of interacting adult agents. Demographic controls limit the presence of locally born children to a 16% maximum of the population, whereas adults make up minimally 84%. A regular influx of imported slaves and contact (per appropriate social hierarchies) between neighboring agents further add to the dynamic population properties. Linguistic mechanisms (e.g., processing and acquiring elements for the lexicon) are maximally operative for child L1 acquisition, but are constrained for adults with respect to acquisition of L2 grammatical inflection markers. The language-learning algorithm operates as follows: the model is initialized by generating a diverse population of monolingual European and African adults for the plantation environment. Contact is then instantiated via the movement rule and is carried out in the same manner as in Experiment I. In contrast to Experiment I however, following 12 learning cycles, interacting agents of opposite genders when both specified as [+fertile], may also produce offspring. Children from unions begin to appear in the environment. A surviving child, such as child agent (a), can enter into a linguistic exchange with any agent 5 years or older. Child agent (a) receives an utterance from adult agent AA. Child agent (a) does not possess any items in his/her lexicon and consequently, stores the words from AA's utterance as separate components, as stems and grammatical affixes, in working memory. As vocabulary is accumulated, it will eventually pass to the child's long-term memory of the lexicon. This language-learning cycle is completed, and the algorithm can be repeated for any number of iterations. As the child agent matures, the L1 child acquisition resources diminish and will be replaced by L2 adult capacities. The outcome of this experiment is based on agent activity spanning 7,000 iterations.

Results

Screenshots of the average lexicon are shown in Figures 8 and 9, representing local level, the internal-language of an average adult inhabitant in the populat The average speaker is statistically a locally born adult male field slave. Figu illustrates the composite of European- and African-language words (stems) in individual's lexicon over time. At approximately t_{500}, the average internal-langu word inventory exhibits an across-the-board increase. While the average adult maintains an amalgam of African-language items, there is an incremental incr of European-language items. From the onset of contact, Fon (A-language) Kikongo (B-language) constitute the majority of vocabulary items in the ave adult lexicon, with European (English) elements growing to third place over ti The category of *"average number of other African words,"* is gradually overt by the rising number of European (English) words.

Figure 9 highlights internal-language over time of an average adult's knowledg inflectional (grammatical) markers. The average individual shows full knowl of African-language inflections within the first few time steps. While the st knowledge of African-based markers remains constant over time, the numb European-inflectional affixes in the internal-language increases rapidly to its maximal level by approximately 500 cycles. The result is that an average adu

Figure 8. Composite of European- and African-language words (stems) in ave individual's lexicon over time. Incremental increase of European-language i (darkest line, third from the top) occurs, while average individual maintains a gam of African-language items (all other lines in graph).

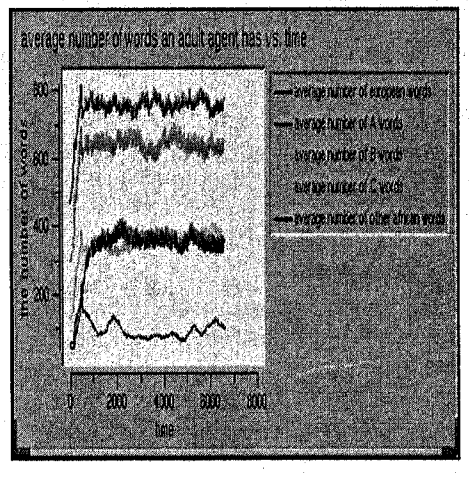
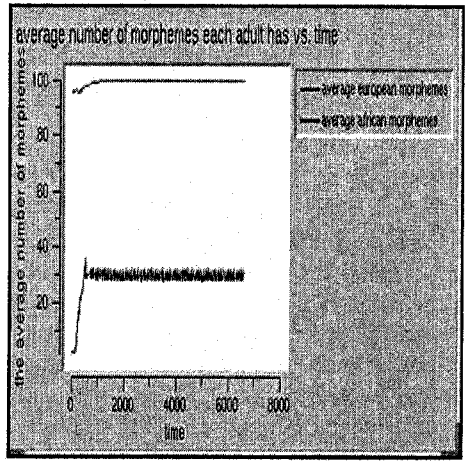


Figure 9. Average individual's knowledge of inflectional markers. Individual shows full knowledge of African-language inflections (top line) within first time-steps. Number of European inflectional affixes (lower line) increases to near maximal level by 500 cycles. Average adult in this setting comes to possess complete knowledge of both African-language- and English-based inflectional verb paradigms, reflecting a feature of bilingualism.

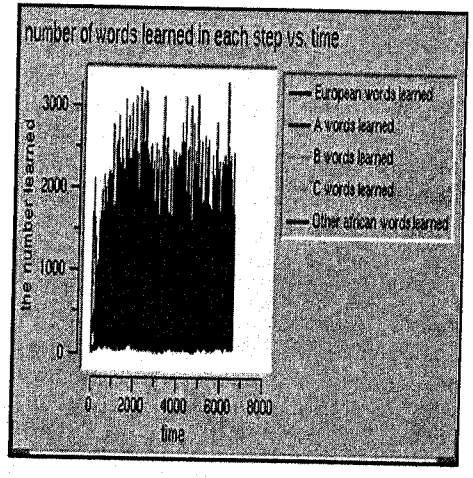


this setting comes to possess an internal-language with complete knowledge of both African-language- and English-based inflectional verb paradigms.

Figure 10 monitors the macro-level, or external-language, vocabulary acquisition process across the total population, adults and children over 7,000 cycles. At t_{500}, robust graph activity indicates that European-based stems are the most frequent vocabulary items acquired in the overall population, despite the presence of the more statistically prominent language of the plantation, Fon. The acquisition of European vocabulary consistently outpaces Fon and all other African-language stems in terms of quantities acquired among plantation inhabitants. This external-language information is doubly useful in that it also indicates the range of vocabulary input that L1 children and L2 adult learners in this context would encounter in the community at any given period of time.

Figure 11 charts external-language acquisition of inflectional markers across the population at each time step. In the course of the first 1,000 cycles, the African-language inflectional particles are learned in the population at higher frequencies than the corresponding European forms. However, a consistently high rate of inflectional learning for both African and European (English) grammars is illustrated in the

Figure 10. Vocabulary acquisition across total population of adults and c over 7000 cycles. At t_{500}, European-based stems (prominent dark area) a frequent vocabulary items acquired in overall population, and their acq consistently outpaces all African-language stems in quantities acquired plantation inhabitants.

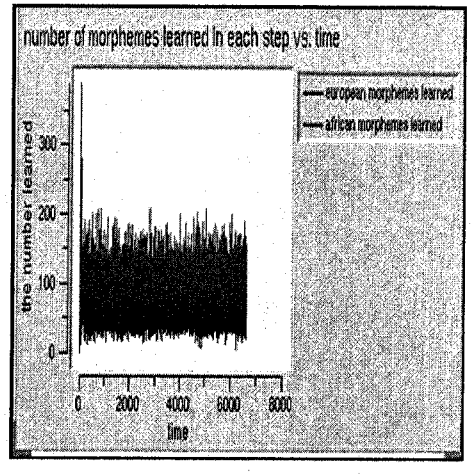


population over time. As an indicator of external-language knowledge of matical affixes at any given period in the population, Figure 11 also provides insight into the type of inflectional features that L1 children and incoming L2 learners encounter on average as linguistic input in the plantation setting. F perspective of language acquisition, the situation is interesting, since a comn of speakers equipped with knowledge of two stable inflectional systems can p tially transmit competing or highly redundant grammatical data in communi encounters. These issues receive further elaboration in the following section

Discussion

Based on criteria of the "imperfect L2 acquisition" hypothesis in Experiment ABM outcomes did not result in a creole language with the *"prototypical crec fects* (e.g., subject-verb-object word order, a largely European [English] *supers*

Figure11. Acquisition of inflectional markers across total population of adults and children over time. African-language inflectional markers (shown as slightly brighter color on top) initially are learned at higher frequencies than European forms (darker color on bottom). After initial 1000 cycles, a consistently high rate of inflectional learning for both African and European grammars occurs over time, reflecting an aspect of societal bilingualism.



and African language *substrates* in the form of [limited] inflectional particles and markers)" on par with Sranan structures. However, a new L2 form spontaneously surfaces as the external-language in the ABM plantation in this context. Comparing internal- and external-language outcomes in Experiment I, the average individual's L2 lexicon is relatively larger and more "complex (i.e., containing more vocabulary items and inflections)" than that of the general population. For several reasons, however, the internal-language state falls short of being an emergent creole: (1) the number of words stored in the L2 Internal-language lexicon on average is scant; (2) no discernible change in the general pattern of substrate versus superstrate vocabulary storage arises over time; and (3) substantial feature expansion (e.g., further acquisition of grammatical markers) does not materialize. Preliminarily, the resulting internal-language structures most resemble an African-based pidgin, based on the reduced quantity of L2 vocabulary present. However, the availability of L1 inflection may qualify more as a type of stable expanded pidgin that has emerged as the "L2" grammar used by the average plantation inhabitant when he/she is not communicating in their native tongue. The external-language clearly exhibits prototypical pidgin characteristics, since the vocabulary is quite limited and concurrently, no inflection exists. The vocabulary consists of a subset of items

shared across the total population. While this pidgin—as most pidgins—em abruptly (within 24 cycles), it is quite stable. All told, an interesting dynamic u between the relatively "sophisticated" internal L2 knowledge of the average sp which includes a scant acquisition of L2 inflectional markers, and the pared external L2 repertoire with no inflection which arises in the overall populatic particular note is the rapid diffusion and stability of the pidgin variety throu the general population.

Turning to Experiment II, contrary to LBH claims, these outcomes do not de strate that children are the lone vehicles of (Sranan) creole formation, with or no intervention from adults. Nor do Experiment II results uphold any clair children must have existed in large numbers in the population (per Bickerton, I However, preliminary findings of the ABM do illustrate that when children a years and younger make up between 15%-16% of the total population, plan outcomes towards creole formation are significantly increased. Both interna external-language data indicate that individual and societal vocabularies on av undergo a transformation from a small quantity of knowledge that is purely A language based to knowledge that doubles over time to a robust, yet still uns amalgam of European superstrate and African-substrate items. Additional evi for this conclusion is that the earliest signs of expansion required for creole form are never attested in the first 12 cycles of the plantation's existence, when adul the sole inhabitants. Rather, the process begins at a point when locally born chi of the plantation have been present for several cycles and a small mass of yo agents is taking root. Despite the child agent's innate and relatively powerful lan acquisition resources, the LBH claim that creole languages develop abruptly v a single generation of child speakers is never corroborated in the current agent- model. The ABM consistently reflects "prototypical creole effects," which er at a gradual rate. Moreover, the ABM data suggest that individuals with cre vocabulary patterns also exhibit complete and stable knowledge of both A and European (English) inflectional systems. Since there is no overlap or impe loss of either inflectional paradigm, this mental state arguably resembles a bili acquisition scenario (Bhatia & Ritchie, 1999; Hamers & Blanc, 2001). Follc Sebba (1997, p. 179), it is reasonable to assume that children in plantation se spoke two L1s: one as the evolving creole, and the other that reflects their ca ers' native language. Insofar as individual "bilingual" competence correlates community-wide creole formation over time, these preliminary findings pr new insights for creole language development in certain contexts. The ABM the door for in-depth research on questions of the young child's (inherent) ca to acquire two or more languages with relative ease. To the extent that a lan bioprogram exists, it may best conceptualized as an expansive blueprint tc bilingualism, rather than its present formulation as a "universal" (monolin grammar.

Conclusion

The current study represents preliminary stages of research which examine underlying cognitive and social mechanisms in real-world language acquisition by utilizing the CAS approach. This work illustrates that it is possible to reconstruct historical contexts in the investigation of language emergence and development. Large-scale effects were produced in the plantation domain as populations of agents interacted and adapted locally in various ways within a CAS environment. Based on micro-specifications of agents, the environment, and rules of behavior in the model, innovative macro-structures and collective behaviors were generated in the system. Thus, the emergent property of the CAS—in this case, of growing linguistic structures in the computer is achieved in the present study.

Possible criticisms of the CAS framework could include the notion that such models are path dependent, in that the results are shaped by the precise initial conditions chosen. However, this assessment obviously does not hold for experiments carried out in the current study. As demonstrated by the unexpected, yet sound, outcomes of the African-based pidgin in Experiment I and bilingualism in Experiment II, with a CAS it is not trivial, and sometimes it is impossible to determine what behavior will be generated, even with relatively simple CAS such as cellular automata (Wolfram, 2002).

Regarding implementation of ABM, it must be acknowledged that while principled and valid results were obtained with the model, the findings do not closely mirror the base case output of Sranan Tongo. Given that parameters are not inherent properties of the system to be modeled, but rather theoretical constructs used by the researcher to describe the system, it may be the case that the model's parameters require further refinement and manipulation in order to generate a matching outcome that closely corresponds to the real-world system. For instance, the present ABM's moment rule implies that physical distance is directly related to social interaction, such that the rule sets the stage for interaction only between bordering neighbors, as close proximity is viewed as a logical, though no doubt overly simplistic, prerequisite for linguistic encounters. Despite these close encounters, neighbors in the model do not blindly interact as might be predicted; rather, social factors also constrain contact. Secondly, to the extent that identification of the "closest unoccupied cell" is a dynamical process in the model, an agent may randomly cover both large and small distances of the plantation. With each movement, the agent potentially encounters a broad diversity of new neighbors whose distribution in the space may not necessarily be accurate in a historical sense.

Another interpretation is that the results of the experiments do not correspond to the "real system" because fundamental assumptions driving the "imperfect L2 hypothesis" and the LBH themselves may be flawed. In this case, modifications that do not

adhere so closely to these particular frameworks could be tested in multiple and would feasibly yield different results. Specific variations could include

- making linguistic exchanges have direct effects on agents' movement its outcomes, instead of indirectly through social contact;
- "importing" other types of agents (e.g., European immigrants rath exclusively
  African slaves);
- making it possible for individual adult agents to possess variable L2 l capacities and individualized learning algorithms; or
- allowing the agents to acquire linguistic information from lower-status bors under certain circumstances.

Finally, other dimensions of creole formation remain to be addressed in the model. Future directions can be envisioned regarding both the modeling fran and its extended applications. Linguistically, the current framework was ke tively simple and abstract to highlight only grammatical aspects of creole forr The most obvious extensions to the framework concern questions of adc linguistic domains (incorporating sound and meaning modules into the le language faculty) to add to the realism of the language acquisition processes. I the model should also be adaptable to other historic language contact scenar language combinations. Lastly, demographic factors must be fine-tuned to i more historical facts of African and European populations and to pinpoin "critical mass" conditions necessary for triggering individual and populatio creole emergence over time.

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