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The invasion of language: emergence, change and death

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Research into the emergence and evolution of human language has received unprecedented attention during the past 15 years. Efforts to better understand the processes of language emergence and evolution have proceeded in two main directions: from the top-down (linguists) and from the bottom-up (cognitive scientists). Language can be viewed as an invading process that has had profound impact on the human phenotype at all levels, from the structure of the brain to modes of cultural interaction. In our view, the most effective way to form a connection between the two efforts (essential if theories for language evolution are to reflect the constraints imposed on language by the brain) lies in computational modelling, an approach that enables numerous hypotheses to be explored and tested against objective criteria and which suggest productive paths for empirical researchers to then follow. Here, with the aim of promoting the cross-fertilization of ideas across disciplines, we review some of the recent research that has made use of computational methods in three principal areas of research into language evolution: language emergence, language change, and language death.

How does language evolve?

Language is the most distinctive feature that distinguishes humans from other animals. All human cultures have spoken language, although relatively few cultures have written language. As de Saussure recognized early during the 20th century, language consists of three distinct, but inter-related mechanisms: (i) 'langage', the physical, cognitive and cultural bases for spoken language; (ii) 'langue', the lexical, phonological and grammatical structures of a particular language; and (iii) 'parole', the actual speech produced by a particular individual. How did the language capability ('langage') first arise? Once it had done so, how did spoken language come to invade the cultural behaviour of all humans? When a particular innovation invades the speech of one group of speakers, how does it diffuse to the speech of others? And when a language invades a community in which one or more other languages are spoken, what are the processes by which those languages compete for speakers, sometimes leading to the extinction of a language? Although there is a rich literature on theories of language evolution, our aim here is to highlight a subset of the recent research that has attempted to provide answers to some of the questions mentioned above so as to promote increased collaboration across research disciplines.

Language evolution: historical context for current research

Research into language evolution began with the observation in 1786 by William Jones that Sanskrit, Greek and Latin bear 'a stronger affinity … than could possibly have been produced by accident; so strong indeed, that no philologer could examine them all three, without believing them to have sprung from a common source, which, perhaps, no longer exists.' About 70 years later, soon after Charles Darwin had proposed the theory of natural selection in 1859 [1], the German linguist August Schleicher [2] drew up a 'family tree' to display the course of evolution that he hypothesized had occurred among what are now known as the Indo-European languages. Schleicher's work coincided with a flurry of activity in two main directions: the description and comparison of languages in terms of their grammar, phonology, lexicon and history, and the putting forward of explanations of how human language originated. Had the work of Gregor Mendel in 1865 on the inheritance of biological traits [3] been more widely read and recognized as opening the door to a deeper understanding of how biological evolution operates, the fields of biological and linguistic evolution might well have continued to progress in tandem. However, whereas the core linguistic disciplines continued to be practiced, work on the evolution of language was soon banned from further discussion by the Société de Linguistique de Paris in 1866 for being too speculative.

It was not until another 100 years or so had passed that discussion of language evolution came to the fore again, with the proposal by Hockett in 1960 of a set of 13 design features that exist in all human languages but that are only partially present in the communication systems of other animals [4]. These include semanticity, the use of an utterance to convey meaning through the use of symbols; and displacement, the reference to objects or actions that are displaced in time from 'now' or in space from 'here'. Hockett suggested an evolutionary trajectory by which these design features might have evolved in the transition from an animal communication system to modern human

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language. Hockett's work was followed in 1975 by the Conference on Evolutionary Origins of Language organized by the New York Academy of Sciences [5] and, more recently, by the on-going series of conferences on The Evolution of Language, the last of which was held during the Summer of 2004 in Leipzig, Germany. Thus, in spite of >200 years having elapsed since a scientific understanding of how languages evolve was first broached, the field of evolutionary linguistics is still young.

A further shift was initiated by James Hurford's 1989 paper on computational modelling of the evolution of the Saussurean sign [6], the arbitrary association between meaning and spoken utterance. Hurford carried out computer simulations to show how different learning strategies affect the efficiency with which a group of individuals can acquire a shared language. Similar computational approaches lie at the heart of much work on language evolution because they enable the potential impact of different hypothesized evolutionary processes on a linguistic system to be assessed objectively. Numerous articles, reviews and anthologies on language evolution have followed (e.g. [7–10]), some focusing entirely on the use of computational methods (e.g. [11]). We look here at the impact of recent research on three particular issues regarding the invasion of language: (i) the invasion of the language capability; (ii) the invasion, competition and subsequent death of languages; and (iii) the invasion of linguistic innovations.

Invasion of the language capability

It is now widely believed that modern language had already emerged by the time of the 'cultural explosion' that occurred ~50 000 years ago as the Middle Paleolithic period gave way to the Upper Paleolithic period, when various artistic, funerary and other cultural innovations first appeared. Indeed, the emergence of language is considered by some to have been the primary cause of this 'cultural explosion' (e.g. [12]). The earliest fossilized remains of anatomically modern humans that have been discovered so far, found in Herto, Ethiopia, however, date from ~160 000 years ago [13,14]. It is probable that modern language first invaded human behaviour sometime during this ~110 000 year window [15,16]. This also fits quite well with the time depth (the elapsed time since a particular event) of <120 000 years within which the human version of the *FOXP2* gene, the so-called 'grammar gene', is estimated to have become fixed [17], having undergone strong positive selection since the human lineage split from that of the chimpanzee, resulting in two amino acid changes. *FOXP2*, whose position on chromosome 7 was mapped in 1998 [18], has been implicated as having a major role in the sequencing of orofacial movements as well as in the formation of linguistic morpho-syntax [19] and in comprehension [20]. Numerous issues that relate to *FOXP2* are reviewed in [21].

Several authors have made use of computational simulations to model the emergence of different aspects of language, including the lexicon (e.g. [6,22,23]) and grammar (e.g. [24–26]). However, another important piece in the puzzle of how modern language emerged (which is the focus of our discussion here) is the question of whether the language capability first invaded at a single location and then diffused across the entire globe ('monogenesis'), or whether language independently invaded at multiple locations before diffusing ('polygenesis'). Controversially, several linguists, notably Joseph Greenberg, Merritt Ruhlen and their collaborators, have devoted much effort toward finding evidence for a single ancestral language for all the extant languages (e.g. [27,28]), often called 'proto-Sapiens' or 'proto-World'. Several papers focus specifically on identifying the basic word order of the hypothesized ancestral proto-language (e.g. [29,30]), believed to be subject–object–verb, from the distribution of the basic word orders of the extant languages, although many researchers hold that this distribution can be explained in terms of the ease with which the different basic word orders can be learned (e.g. [31,32]). Monogenesis remains the preferred hypothesis of many linguists, although there is, as yet, no widely accepted empirical evidence that modern languages do descend from a common ancestral proto-language.

In an attempt to evaluate the relative likelihood of these two hypotheses, Freedman and Wang [33] adopted a probabilistic line of argumentation. In their model, language can invade independently at each of n locations over some fixed period of time. Based on the assumption that the probability of invasion at each location has the same small value, p, they calculate the probability of monogenesis and of polygenesis. They find that the relative likelihood of polygenesis depends only on the expected number of emergence locations, np. In this model, if the expected number of emergence locations exceeds ~4/3, polygenesis is the more probable hypothesis. The authors therefore conclude that polygenesis cannot be excluded as a plausible hypothesis.

Freedman and Wang acknowledge that their model is overly simple, treating a language as a single monolithic entity, rather than as the functional product of multiple interlocking cognitive, physiological and cultural capabilities, and ignoring the effect of diffusion of language from one location to another on the relative likelihood of polygenetic emergence. However, a recent refinement to their approach by Coupé and Hombert does deal with these two aspects [34]. Coupé and Hombert model the invasion of 'linguistic strategies', incremental components to language that reflect advances in acquired cognitive reasoning, and the diffusion of such strategies between autonomous groups of language-capable human hunter-gatherer agents. An architecture involving a network of incremental evolutionary steps necessary for the emergence of modern language has been proposed by Jackendoff [35]; the steps overlap with the design features of Hockett [4], and include, for example, symbolization, and hierarchical phrase structure capabilities.

Based on an average hunter-gatherer group size of ~25 individuals, Coupé and Hombert use population density data for contemporary and Palaeolithic (estimated) hunter-gatherer groups to model the frequency of contact between groups as they coexist on and move about some land mass, modelled as a finite, bounded plain. In the model, groups come into contact whenever the distance separating them is less than a certain threshold, thereby acquiring linguistic strategies from each other. The relative probabilities of monogenesis and polygenesis of a linguistic strategy are then assessed by comparing the probability of emergence of a strategy in some group against the rate of contact-induced diffusion. The authors argue that the population density of hunter-gatherer groups was probably small and, consequently, contact between groups correspondingly rare, such that the diffusion of a monogenetically emergent strategy across an entire population would have also been comparatively rare. For example, for a population consisting of 1000 groups spread over a 2 000 000 km^2 range, moving with speed 5 km y^{-1}, a contact threshold distance of 10 km and 0.01 y^{-1} probability of emergence at each location, the estimated expected time of total diffusion of a linguistic strategy is ~23 000 years. Although other sets of plausible parameter values give smaller expected times for total diffusion, it is likely that, in the transition from the communication systems of early hominids to fully modern language, some linguistic strategies emerged polygenetically. Nevertheless, some key steps, such as the design features described by Hockett [4], probably emerged monogenetically and subsequently invaded the existing language.

As Coupé and Hombert discuss, one further possibility is that various linguistic strategies arose at different locations independently, giving rise to a polygenetic emergence of human language, but that, through competition and cultural selection, akin to the process of biological drift (but note that, in linguistics, the term 'drift' usually follows Sapir's definition of 'a trend which is not too regular but still to some extent predictable' [36]), one particular set of linguistic strategies gave rise to a single proto-language from which all the modern languages then descended. Language competition and death would therefore have had a vital role in the selection and shaping of this proto-language.

Box 1. The dynamics of language competition

In the Abrams and Strogatz model for language competition [43], speakers select either of two languages, X or Y, with which to converse with other speakers (Figure Ia). The community is therefore comprised entirely of monolinguals. In the model, speakers can either maintain their proficiency in a particular language or switch to speaking the other language. However, in actual situations of language competition, sociolinguistic interaction between the speakers of one language, X, and a second language, Y, is achieved via bilingual speakers who are proficient in both languages, at least in certain social contexts. The dynamics of the model should therefore be amended to include bilingual speakers:

• Monolingual speakers of either X or Y can choose to maintain their proficiency in that language or else can opt to become proficient in the second language too, without loss of proficiency in their first language (Figure Ib).

• Bilinguals speakers (Z) can choose to remain bilingual or, if proficiency in two languages is considered sufficiently unbeneficial to them, can elect not to use one of the languages to become monolingual in the other.

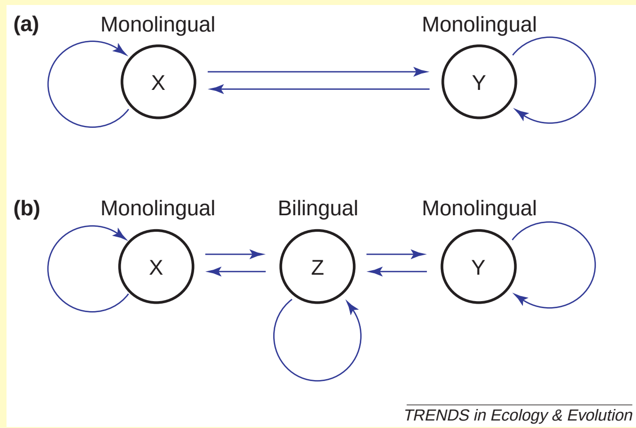

Figure I.

Language competition and death

There are ~6000 languages now spoken in the world [37]. By some estimates, between 50% and 90% of these languages will have become extinct by the end of the 21st century [37]. Although, according to Mufwene [38], this prediction might be somewhat inflated, it is nevertheless likely that increasing numbers of people will respond to socio-economic factors to share a common first language, resulting in a significant loss of linguistic diversity that, over time, might also lead to a corresponding loss of cultural diversity. Although he argues in his review that 'Linguists concerned with the rights of languages must ask themselves whether those rights prevail over the right of speakers to adapt competitively to their new socioeconomic ecologies' [38], Mufwene makes it clear that, in recent years, there has been a great deal of concern over language endangerment and language maintenance [39–42].

However, a new avenue of theoretical research has been opened by Abrams and Strogatz [43] who, in 2003, proposed a simple dynamical system for modelling language endangerment (Box 1). Their model describes the competition between two languages for speakers in a community. The dynamics of the system derive from the assumption that individuals adopt a language with a frequency proportional to its status, a measure of the prestige and socio-economic benefits accrued by speaking that language, and to an increasing function of the number of individuals speaking it. They fit the model to empirical data summarizing the proportions of speakers of each language throughout much of the 20th century collected for several endangered languages: Quechua (threatened by Spanish), Scottish Gaelic (by English), and Welsh (also by English). In spite of the significant weaknesses of this model, not least its neglect of bilingual speakers and of social structure, the fit to the empirical data was exceptional; in each case, the authors found the outlook for the endangered language to be dire.

An extension of the Abrams and Strogatz model, in which the effect of population density is considered, has been proposed by Patriarca and Leppänen [44]. Whereas in the Abrams and Strogatz model the rate of growth of the usage of a certain language was assumed to increase with its number of speakers, in the new model the rate of growth is assumed to differ from location to location depending on the local population density. The new model therefore explicitly deals with the cultural diffusion of language-usage strategy across a heterogeneous

Box 2. Two theories for sound change: the Neogrammarian Hypothesis and Lexical Diffusion

According to the Neogrammarian Hypothesis (Table I), a sound change is lexically abrupt, affecting all words that participate in the sound change simultaneously, and phonetically continuous, the sound being pronounced with a continuum of variants as it changes over time. According to the theory of Lexical Diffusion (Table I), however, a sound change is lexically gradual, with a change progressing word by word from speaker to speaker, and phonetically abrupt, with the pronunciation of a particular word by a particular person changing instantaneously (although the theory also allows for phonetically gradual changes, particularly for vowels).

An example of a sound change is the change from /i:/ to /ai/ that occurred during the Great Vowel Shift as Middle English transformed into Modern English. For example, the word 'mice', now pronounced /mais/, was formerly pronounced /mi:s/. This particular sound change was phonetically gradual, starting during the 15th century but only completing during the 18th century.

Table I. A comparison of the Neogrammarian Hypothesis and Lexical Diffusion

Neogrammarian Hypothesis	Lexical Diffusion
Lexically abrupt	Lexically gradual
Phonetically gradual	Phonetically abrupt or gradual
All words change simultaneously	Words change one by one
Change in pronunciation is gradual	Change in pronunciation can be instantaneous
e.g. for /i:/→/ai/,	e.g. for /i:/→/ai/,
[i:]→[ɪi]→[ei]→[ɛi]→[ai]	[i:]→[ai]

community. The formulation of Patriarca and Leppänen leads to a description of the system in terms of a set of 1-dimensional reaction diffusion equations; such dynamical systems have been used to model, for instance, the behaviour of chemical reactions such as the Belousov–Zhabotinsky reaction, a non-linear oscillatory reaction that results in a series of expanding concentric rings of alternating colours. The authors conclude that multiple languages can coexist by acquiring speakers in distinct geographical locations.

Other works on the modelling of language competition have often been grounded in the innatist approach, in which the cognitive processes that make language possible are believed to have evolved in humans specifically to support language. For example, Nowak and colleagues (e.g. [45,46]) have examined competition within the innatist framework of Universal Grammar, the hypothesized set of grammars that can be learned by the human brain. Similar to the models of Abrams and Strogatz [43] and of Patriarca and Leppänen [44], these works are formulated using dynamical systems of coupled differential equations. Among other results, they show that, for a system of competing languages for which imperfect learning of a language by children is the main driving force for language evolution, language death is not an inevitable outcome. Rather, the authors show that the system can fluctuate chaotically over time between different dominant languages [46].

The works described above [43–46] are formal mathematical models that only loosely reflect the sociolinguistic structure of systems of language competition. For these types of formal model to contribute to our better understanding of language competition and death, they should incorporate sociolinguistic factors such as social structure, the multiple registers (subsets of a language used in different social contexts) of speech and the impact of heterogeneous strategies, both at the level of individual speakers and at the level of policy-makers. Recently, empirically grounded theories of social structure and interaction have been augmented by dynamical system models (e.g. [47]) and network theoretic models (e.g. [48–50]). Several models that address aspects of social structure have already been reported in the literature on language evolution (e.g. [26,51,52]).

Language change

One of the most noticeable ways in which languages can change is by changes in sound; witness the effect of the sound changes known as Grimm's laws on the English language as it diverged from German so that we now have, for example, 'apple' in English but 'apfel' in German. The Neogrammarian Hypothesis that sound change is lexically abrupt but phonetically gradual held sway until 1969, when Wang [53] proposed the theory of Lexical Diffusion, which predicts sound change to be lexically gradual but phonetically abrupt or, in the case of a sound change involving a vowel, lexically and phonetically gradual (Box 2).

One of the first studies of lexical diffusion was by Sherman [54], who examined the invasion of diatones in English from the 16th Century through till the 20th Century. An example of a diatone is the noun–verb pair /ˈpermɪt/ (stress on the first syllable; a noun, e.g. 'you need a permit to do that'; for a description of the phonetic symbols used to indicate the pronunciations of words see the website of the International Phonetic Association: http://www.arts.gla.ac.uk/ipa/ipa.html) and /perˈmɪt/ (stress on the second syllable; a verb, e.g. 'I permit you to do that'), which differ in pronunciation only in terms of their stress but which are both written in English as 'permit'; before the change, both words were pronounced in the same way, with the stress on the second syllable. A plot of the number of diatones over time suggested that the usage of diatones gradually increased with an S-shaped progression, a pattern that is commonly observed. Innovations also occur in grammatical systems. More recent studies, such as those by Kroch [55] and Ogura [56] on the diffusion of a particular grammatical construction, periphrastic *do* (as in 'I do want an apple') in English have also shown the change to proceed according to an S-shaped curve. Cavalli-Sforza and Feldman [57] have noted that the invasion of a linguistic innovation has much the same properties as the invasion of a virus, an idea that has provided much inspiration for language modellers.

Box 3. Modelling the snowball effect

In the model for sound change presented in [60], a set of *n* words that can potentially participate in a sound change can take either of two forms: the unchanged form (U) or the changed form (C). The proportion of speakers adopting the unchanged form of word *i* at time *t* is denoted by $u_i(t)$ and the proportion adopting the changed form by $c_i(t)$.

In Figure Ia, a word is assumed to participate in the sound change according to the proportion of speakers who use the unchanged form of that word, reflecting the pressure on speakers to imitate the particular innovations adopted by other speakers, as in Shen's model [58], and to the proportions of speakers who use the changed forms for the other words participating in the change, reflecting the pressure on speakers to maintain a consistent sound system. The parameters α_{ij} denote the impact of the frequency of changed forms of word *i* on the rate of adoption of changed forms of word *j*; for $i \neq j$, α_{ij} is termed the 'cross-coupling' of words *i* and *j*, and α_{ii} is termed the 'self-coupling' of word *i*. Over a period of time of duration δt, the increase of usage of the changed form of a particular word is proportional to the combined effect on that word of the weighted frequencies of changed forms of all the words participating in the sound change (Equations I,II):

$$u_i(t+\delta t) = u_i(t) - u_i(t)\left[\sum_{j=1}^{n} \alpha_{ij} c_j(t)\right]\delta t \qquad \text{[Eqn I]}$$

$$c_i(t+\delta t) = c_i(t) + u_i(t)\left[\sum_{j=1}^{n} \alpha_{ij} c_j(t)\right]\delta t \qquad \text{[Eqn II]}$$

Thus, the sound change progresses as more words participate in the change (W-diffusion) and as more speakers adopt the change (S-diffusion). The model is unidirectional because speakers can shift from the unchanged form to the changed form, but not back again.

Figure Ib shows a plot of the proportion of changed forms for each of four words (shown as solid, dash-dot, dashed and dotted lines) as a function of time predicted by the model described above [60]: the cross-coupling was set to 0.20 and the self-coupling to 0.02 for all words; the proportions of changed forms were initialized to 5%, 2%, 0.5% and 0.1%, respectively. Figure Ib indicates the two distinctive features of the snowball effect: (i) words that start to participate in the sound change later do so with increasing frequency, indicated by the decreasing distance between successive curves; and (ii) later words invade the speech of speakers at an ever-increasing rate, indicated by the increasing peak gradient of successive curves. However, it remains to be tested how well this model fits the empirical data. (Figure I adapted, with permission, from [60].)

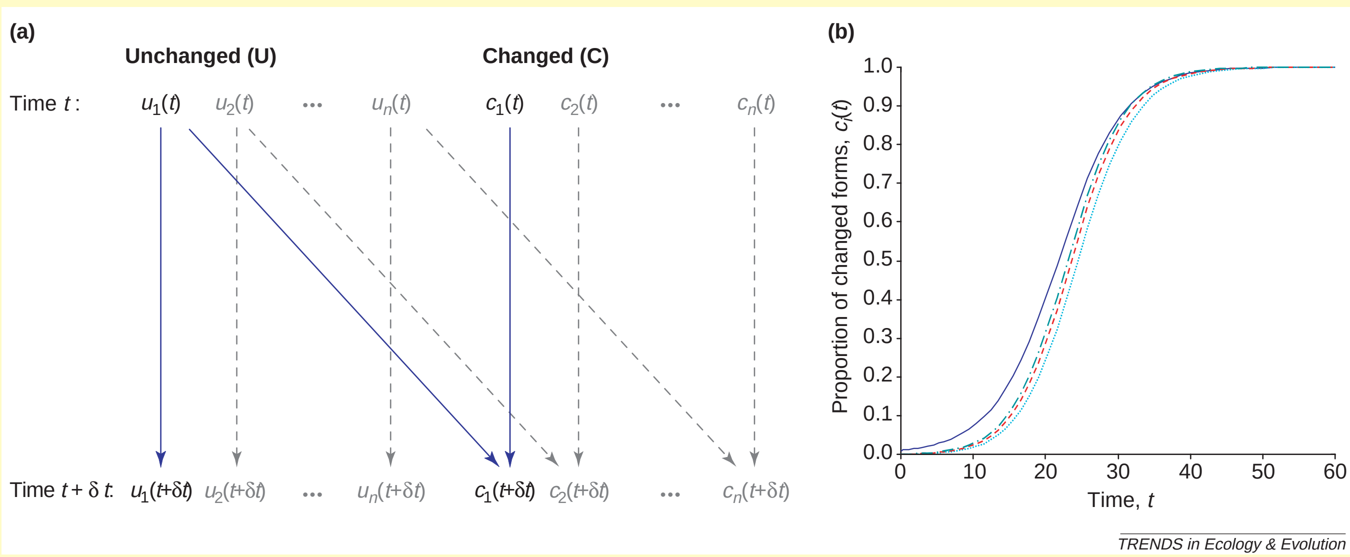

Figure I.

Shen [58] conducted an empirical study of two sound changes that have recently occurred in two dialects of Chinese. One is the merger of the nasalized vowels /ã/ and /ɑ̃/ in the Shanghai dialect; the other is the monophthongization of /øy/ to /ø/ in the Wenzhou dialect (monophthongization is the simplification of two vowel qualities into one vowel quality; e.g. Mandarin 'hao', meaning good, is usually pronounced like English 'how', but is becoming similar to English 'haw' in some dialects). Using the ages of speakers from whom he collected speech data as a virtual indicator of the speech norms in past times, Shen traced the invasion of the sound change across each community. In both cases, he found the progression of the sound change to follow approximately an S-shaped curve. He then proceeded to fit the empirical data to a simple model for sound change. He began by assuming that each word that could potentially participate in the sound change could be pronounced in either of two ways: an unchanged form and a changed form. He then assumed that the proportion of speakers having the changed form for a particular word would increase at a rate proportional to the expected number of contacts between pairs of speakers, one speaker having the unchanged form and the other having the changed form. The solution to this simple system has the number of speakers using the changed form increasing over time according to the S-shaped logistic function, as previously noted by Kroch and Ogura. A significant weakness of this solution, however, is that the predicted change is unidirectional and always completes. In other words, the change is always predicted to invade the entire population, which is not always the case, even for sound change. The diffusion of diatones in British English, for example, has not completed: for example, 'report' is still pronounced as /rɪˈpɔət/ (with the stress on the second syllable) both as a noun and as a verb. Sherman [54] gives a long list of such words.

As a sound change progresses, it invades the lexicon at different rates, both from word to word (W-diffusion) and from speaker to speaker (S-diffusion) [59]. Typically, few words participate in the change initially, but over time, words start to participate in the change with increasing frequency and invade the speech of speakers at an increasing rate, a phenomenon that has been called the 'snowball effect'. Shen's analysis of the data for two sound changes in Chinese showed such an effect by fitting an independent logistic model to each word [58]. However, this ignores the causal effects that changing words have on other words. A first step toward modelling the interaction between words has recently been taken by Wang *et al.* [60] (Box 3).

Taking a different approach, Yang presents a formal statistical model for language change set within the Principles and Parameters framework of Universal Grammar [61]. He takes the position that it is the probability with which child language learners can parse (i.e. use a particular grammar to comprehend) the utterances that they hear and the corresponding selection of an optimal grammar with which to parse future utterances that drives language change. For an innovation that is introduced in one generation such that the linguistic environment is significantly different from that of the previous generation, Yang's model predicts that the innovation invades the succeeding generations again following an S-shaped curve. Once again, however, the model is unidirectional, similar to the examples discussed above.

Summary

The types of computational research discussed here are enabling researchers to develop and refine hypotheses regarding language invasion at all levels, from the initial emergence of modern human language to the endangerment and potential death of extant languages. Computational models are becoming increasingly realistic in terms of the sociolinguistic and cognitive features that they incorporate. To our knowledge, no significant question regarding language evolution has yet been answered incontrovertibly by such models, but they do enable us to concentrate with ever increasing focus on those hypotheses for which definitive evidence might soon be produced.

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