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Towards an integrated science of language

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It has long been assumed that grammar is a system of abstract rules, that the world's languages follow universal patterns, and that we are born with a 'language instinct'. But an alternative paradigm that focuses on how we learn and use language is emerging, overturning these assumptions and many more.

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The philosopher Susan Haack[1] likens science to a crossword puzzle. In crosswords, the harder the clues, the more we benefit from their interrelations: 3 down helps us to solve 5 across and vice versa. This logic underpins the power of integration across methods and levels of explanation throughout the natural sciences. Yet the study of language has too often taken precisely the opposite approach. Research on syntax, semantics, language typology and change, computational linguistics, language processing, child language acquisition and language evolution has become disconnected, and their proposals hopelessly incompatible. But allowing the language sciences to fragment is like trying to solve a crossword by first treating each clue independently, and only trying to fit them together at the very end — a strategy that is surely doomed to fail.

Fortunately, an alternative synthesis is beginning to emerge in the language sciences, fuelled by cross-disciplinary work. This synthesis overturns past assumptions about the nature of grammar, reconnects language processing and learning with basic cognitive principles, and sees language as a product of cultural evolution — not guided by a genetically encoded 'Bauplan'.

Optimism and retreat

The modern era in the study of language began in the 1950s with Noam Chomsky's invention of transformational grammar: a mathematically rigorous system of rules aiming to generate the grammatical sentences of each natural language. Transformational grammar itself underwent various important theoretical developments and soon became associated with some striking claims: that all human languages follow the same deep universal patterns; that this 'universal grammar' is innate and unfolds gradually during language development in the same way that a chicken grows a wing; and that evolution of language is instantaneous, perhaps arising from a sudden large-scale genetic mutation. The generative grammar project initially promised to forge important links across disciplines. Psychologists searched for traces of linguistic transformations in language-processing times; developmentalists tried to interpret child language as generative grammar 'in flux'; engineers tried to incorporate generative grammar into their natural language systems; neuroscientists and geneticists searched for the biological roots of universal grammar; and students of language variation assessed the universality of the supposedly universal principles.

Yet, these initially hopeful developments, and their many variations, soon foundered. Psychologists could find no evidence of transformations. Child language could only fit the generative story with extreme assumptions (for example, children are not making mistakes but simply speaking a language other than the one to which they're exposed; or that two-word utterances are complex sentences with lots of material for some reason deleted). Linguistics seemed unable to assist computer-based natural language processing, as illustrated by the IBM (International Business Machines) engineer, Fred Jelinek, who famously remarked that "Every time we fire a linguist, the performance of our system goes up."[2] Neuroscience could not isolate special machinery for language, and 'language genes' proved illusory. And the world's languages appeared replete with counter-examples to universal patterns[3]. Some researchers valiantly struggled to resolve these problems; but the mainstream reaction was to ignore them. Theoretical linguists, psycholinguists, child-language researchers, computational linguists, biologists interested in language, field linguists, and more, began to diverge, often to the point of mutual theoretical incomprehension. Indeed, mainstream linguistic theory began to actively create distinctions (for example, competence versus performance, core versus periphery, learning a language versus processing that language; language change versus language evolution) that aimed to justify sealing off these different disciplinary perspectives on language from one another.

In the physical and biological sciences, of course, integration and interaction between levels of analysis and diverse data is ubiquitous (particle physicists work with cosmologists; evolutionary theorists with geologists; embryologists with geneticists; and so on). The crossword of nature can only be solved by integration and relentless interaction across disciplines. Many mainstream linguists talk of linguistics as part of biology, or draw parallels between theoretical linguistics and theoretical physics — but the reality could not be more different.

Towards an alternative synthesis

The disintegration of the study of language made us deeply uncomfortable as graduate students at the University of Edinburgh more than two decades ago; and we were by no means alone. Across our own university, and across the world, a variety of heterodox theoretical frameworks, computational models and empirical programmes were beginning to emerge. But these 'minority' approaches have gradually become dominant and, excitingly, common threads are emerging which create the basis for a radically different synthesis in the study of language.

At the heart of this emerging alternative framework are constructions[4], which are learned pairings of form and meaning ranging from meaningful parts of words (such as word endings, for example, '-s', '-ing') and words themselves (for example, 'penguin') to multiword sequences (for example, 'cup of tea') to lexical patterns and schemas (such as, 'the *X*-er, the *Y*-er', for example, 'the bigger, the better'). The quasi-regular nature of such construction grammars allows them to capture both the rule-like patterns as well as the myriad of exceptions that often are excluded by fiat from the old view built on abstract rules. From this point of view, learning a language is learning the skill of using constructions to understand and produce language. So, whereas the traditional perspective viewed the child as a mini-linguist with the daunting task of deducing a formal grammar from limited input, the construction-based framework sees the child as a developing language-user, gradually honing her language-processing skills. This requires no putative universal grammar but, instead, sensitivity to multiple sources of probabilistic information available in the linguistic input: from the sound of words to their co-occurrence patterns to information from semantic and pragmatic contexts. Computational analyses of speech addressed to children have revealed that there is much more information available to the child than previously assumed[5]. For example, word categories and meanings can partly be inferred through statistical analysis of which words and phrases occur together; and cross-linguistic analyses show that nouns and verbs tend to sound different, with subsequent experiments showing that children use such cues to help learn new words, and that adults also rely on them during sentence processing[6].

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The ability to muster and integrate information as quickly as possible is crucial given the here-and-now nature of language. We have all experienced losing the thread of a conversation simply because our attention was diverted for even a moment. Our memory for auditory information is incredibly short-lived, and new information rapidly obliterates the old, so that we even struggle to recall a sequence of only a handful of elements — yet speech comes at us at a very rapid rate (about 150 words per minute). So, the brain must process new information rapidly, or it is lost forever. This 'Now-or-Never bottleneck' may explain why language structure and processing is highly local in the linguistic signal (for example, why speech sounds are grouped into words; why plural and tense-markers are usually directly adjacent to the words they modify; why adjacent words clump into phrases, and so on); and, from this standpoint, language acquisition involves inferring localized patterns, through the rapid integration of probabilistic information[7].

Intriguingly, engineers working on systems that need to respond in real-time to human speech have also arrived at similar local pattern-matching solutions. Take, for example, the speech recognition systems that we all now have on our cell phones. If you ask what the temperature is outside, a delay of even a couple of seconds makes the answer feel awkward and unnatural. Artificial speech recognition systems therefore must also process language in the here-and-now. The strategies they employ are revealing: they rely on probabilistic pattern matching with respect to individual words, multiword strings, or parts of strings with 'wild cards' (for example, 'what's your *X*', where *X* can be instantiated by somebody's name), but not syntactic trees generated by abstract rules. They also incorporate as much prior context or other background knowledge (for example, content area being discussed) as possible to ensure that they are right-first-time (or at least, most of the time). So, paradoxically, any computer that we can really converse with, like HAL in Stanley Kubrick's *2001: A Space Odyssey*, may need to build in a human-like Now-or-Never bottleneck.

Language and cultural evolution

The construction-based framework also naturally accommodates the awe-inspiring diversity of the world's languages[3]. Languages variously employ tones, clicks, or manual signs to signal differences in meaning; some apparently lacking the noun–verb distinction (for example, Straits Salish), whereas others have a proliferation of fine-grained syntactic categories (for example, Tzeltal); some are without morphology (for example, Mandarin), while others use it to pack a whole sentence into a single word (for example, Cayuga). Of course, cross-linguistically recurring patterns do emerge due to similarity in cognitive constraints and culture/history, but such patterns are probabilistic tendencies, not the rigid properties of a universal grammar. Individual languages change over time through processes of cultural evolution, in ways that resemble biological evolution, as already noted by Darwin[8]. Constructions that are more easily squeezed through the Now-or-Never bottleneck, or more communicatively useful, will tend to proliferate. Thus, the origin of language requires no genetic leap, but the cumulative cultural evolution of language itself[6].

The cultural evolution perspective has received empirical support from a new breed of lab-based experiments with human participants[9]. In a typical study, what is learned by one person is transmitted to the next, similar to the childhood game of telephone, leading to language-like structure emerging across 'generations' of learners. Importantly, this perspective explains how children can learn languages accurately without an innate language instinct. Language acquisition is possible because languages have been selected to be as learnable as possible — and hence to fit the child's processing and learning biases. Each new language learner therefore needs only to follow in the footsteps of previous generations of learners with the very same biases[6].

Changing focus

The traditional perspective on language sees the phenomena studied by the construction-based approach as marginal: as ignoring the highly abstract universal linguistic patterns captured by universal grammar, and focusing on language use rather than on abstract knowledge of language. Many of the phenomena that have become the focus of syntactic theory are so abstract that they are often difficult to connect even with specific linguistic phenomena, let alone with experiments on how people process language or observations of how children learn their native tongue.

But are such abstract principles necessary to capture the core structure of the language? The linguist Peter Culicover[10] argues that if construction-based theories capture the irregularity and idiosyncrasy of language, then those same methods will easily capture any regular grammatical core.

Moving forward

Despite the shifting theoretical picture in the language sciences, assumptions about universal grammar are still being generalized to other fields. Scholars have suggested innate grammars for music, morality and even religion. We suggest that an updated analogy with language reveals a different perspective: that these too are products of cultural evolution shaped by the biases of the brain.

Reintegrating the language sciences also presents huge opportunities for linking together different aspects of the study of language: viewing language acquisition as the process of acquiring the ability to process specific constructions; seeing language evolution as shaped by the processing and learning biases of the brain; providing a historical explanation for language change and variation based on the diffusion and modification of constructions; and reconnecting linguistics with the construction of workable computer language processing systems[6]. Although such reintegration has been hampered in the past by the fragmentation of the study of language across university departments, conferences and funding bodies, the tide is now shifting and an integrated science of language is gradually emerging. We envisage a future where broad, interdisciplinary departments of language science will become increasingly common. ❐

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Competing interests

The authors declare no competing interests.