Building the tower of babble

by

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Language is an apparent miracle. Children master it with exceptional ease, while simultaneously struggling to walk, hold a fork, and recognize that others have thoughts and emotions that differ from their own. They perform, with near perfection, mental computations and generalizations about language which are virtually impossible for state of the art computers. They grasp the tree-like phrase structure of language even though their parents have never taught them, and most probably couldn't even if they wanted to (such properties of language are not the stuff of school education). And children babble on about the present, past and future, creating imaginary worlds that no one but they can see.

Children eventually grow up, become masters of one or more languages, and use the sounds from their mouths or gestures from their hands, to convey information, exchange ideas, and debate. Some of these grown up children descended on the Institute for Advanced Study in Princeton on May 2001 to use their language to better understand its miraculous appearance in the child, as well as its evolution in the species.

A key question in all of the approaches presented at the conference was: what are the core computations underlying language evolution and language learning? For some, this problem breaks down into an analysis of how organisms, including humans, communicate, whereas for others, it boils down to a set of computations that may be used to communicate, but may not have evolved for communication.

Ray Jackendoff kicked off the meeting with a broad sweeping perspective on language evolution, arguing that it evolved by means of an accumulation of gradual innovations. A first link in this chain is a primitive, one-word proto-language, a system that is to some extent shared with other (wild) animals, as well as the few enculturated apes and dolphins that have been trained by humans. Toward the end of the chain is a final link which provides the capacity for a modern, syntactically structured language. On Jackendoff's view, this link is missing in animals. A crucial question then arises: which links in the chain do we share with animals and which evolved uniquely within out species?

Continuing with the evolutionary theme, Marc Hauser approached the problem by using what is known as the Chomsky hierarchy, a formal approach to language that explores different computational capacities [3]. A first cut is between finite and phrase structure grammars, the former restricted to local dependencies between variables (e.g., conditional probabilities), the latter providing the initial stages of a recursive system with long distance relations. Based on experiments with captive primates, Hauser showed that monkeys such as cotton-top tamarins can compute several finite state grammars, but may have difficulties with phrase structures. If correct, this suggests that one point of evolutionary departure between humans and other animals lies in our capacity for recursion.

Dorothy Cheney provided a different approach to the evolutionary problem, showing how animals naturally deploy their vocalizations and the extent to which their calls are word-like. Non-human primates such as vervet monkeys and baboons appear to have a large vocal repertoire, but they apparently never talk about anything which is not directly relevant to their present state [4]. They seem to lack an ability or desire to communicate about hypothetical things or events; however, our knowledge about the meaning of their vocalizations is largely constrained by the current methodology. Cheney also pointed out that even if monkeys had a large and open ended repertoire of referential signals, they apparently lack an understanding of other minds. Consequently, although they are effective communicators, they do so on the basis of how others behave, not on the basis of how others think.

For many, language is built out of other computational capacities, and especially, mechanisms specialized for learning. Leslie Valiant is developing a formal system that aims to relate the problems of logical reasoning with those of statistical learning [5]. The goal of this work is to explain how computational models of brain function can account for patterns of learning and memory, thereby providing a characterization of the computational building blocks of higher cognitive functions such as language. Daniel Osherson used formal logic and learning theory to study human judgment and reasoning by humans when evaluating competing information [6]. In one particularly elegant example, he described a game between Nature and a scientist, and then proposed a new inductive inquiry model that captured the learning process.

A more applied approach to the problem of language learning was taken by Deb Roy, who reported on his progress in building machines that learn to communicate in human-like ways [7]. In an attempt to explore how human infants pick out different words from their mother's stream of speech, Roy has designed robots that operate across different channels of perception, using as input an audio-video recording of mothers communicating with their infants. The learning algorithms successfully picked out the words from the mother's speech, especially if both auditory and visual information were provided, as opposed to auditory information alone.

Understanding how lexical items are perceived is closely linked with questions of phonology. The physical act of uttering words imposes certain restrictions on what is allowed in speech. Louis Goldstein suggested that the basic units of phonological contrast are gestures [8]. In his models, utterances emerge as organized patterns of gestures, in which gestural units may overlap in time and vary in magnitude.

Mastering a language's phonology as well as its lexicon are important components of language acquisition, but there is an even more complex task which each child has to solve, namely, learning the *grammar*. Kenneth Wexler presented a formal analysis of grammatical errors by children, placing these results in the context of the *principles and parameters theory.* Results showed that when you look at production data, children appear to have a host of grammatical parameters correctly adjusted from the onset. Consequently, language acquisition appears to unfold as a consequence of positive examples or input, as opposed to feedback through instruction or correction.

Alan Prince and Bruce Tesar argued for a different approach to language acquisition, namely the framework of *optimality theory* [10], [11]. This framework is based on a suite of constraints (as opposed to principles and parameters) that are functionally ranked in terms of their importance. Tesar and Prince described a learning algorithm where only the ranking order of the constraints played a role in evaluating the output candidates. This approach also provides a high degree of predictive power with respect to accounting for patterns of language use, thereby raising the problem of how best to distinguish between optimality as opposed to principles and parameters approaches. Paul Smolensky drew an intriguing connection between optimality theory, neural networks and evolution. Based on a theoretical model, he showed some of the possible ways in which genes might encode information about brain structures, which in turn give rise to language.

Partha Niyogi has developed an original mathematical approach to grammar learning which is based on Chomsky's theory of generative linguistics as well as the theory of learning and dynamical systems [12]. Niyogi outlined a research program for studying historical linguistics in the context of population learning. His models have the advantage of being amenable to an analytical treatment, and at the same time they are easily compared with the large corpus of existing linguistic data. Charles Yang used the framework of Niyogi to create a quantitative model of language acquisition. This model helps explain why children make certain mistakes and sheds light on the actual learning mechanisms used by children in the process of acquiring a language [13]. According to Yang, there is no clear cut distinction between different grammars in the child's universal grammar. Rather, at each stage of the language acquisition process the child finds itself speaking a *mixture* of several grammars.

A different approach to understanding the mechanisms underlying language evolution and acquisition comes from the study of pidgins and creoles. According to Salikoko Mufwene, language evolution is much like the process of speciation: languages can experience selective advantage or disadvantage, compete, adapt and vary, in analogy with the corresponding processes in population biology [14]. David Lightfoot emphasized that there are different modes of language evolution, drawing on parallels from recent studies of organismal evolution [15]. Languages are constantly changing in a gradual, chaotic fashion. The corresponding variations are small and based on accidental factors that may have no functional explanation. On the other hand, languages sometimes change abruptly, several things changing at the same time, and then settle into a period of stasis, again paralleling the paleontological notion of ”punctuated equilibrium”.

Martin Nowak and Natalia Komarova [16] have integrated ideas from evolutionary biology and current learning theory into a series of mathematical models of language acquisition and evolution. The concept of *biological fitness* is at the basis of their approach. At the core of their theory is the idea that clearly articulated speech is associated with a fitness benefit, and that language variability arises because of learning errors. Komarova and Nowak identified the basic cognitive requirements to develop and maintain a coherent language, and then showed how this general framework could be applied to other aspects of language evolution, including the acquisition of a lexicon [17]. Scott Weinstein took this framework one step further by showing how language and learning acquisition devices might co-evolve. The fine interplay between acquired language and inherited learning mechanisms may be responsible for some unexplained historical language changes.

The aim of the meeting was to discuss to what extent evolutionary biology and learning theory can shed light on the nature of human language and its origins. It has become clear that a new field is emerging which makes use of theories of formal linguistics, machine learning and evolutionary biology. Mathematics is, as is often the case, the "language" of the new field, and the phenomenological work is its inspiration. But we must be careful, as Stephen Anderson [18] argued, to avoid the pitfalls of unconstrained speculation, which is so deeply tempting whenever the grand questions of "origins", "nature" or "evolution" are considered.

The miracle of language, and its deeply perplexing origins, was eloquently brought home by William Wang [19], who recounted the tale of Chairman Mao and his farewell greeting to a group of western guests. Perhaps with a bit of poetic license, and undoubtedly a set of filtered lens, the guests heard Mao to say: *"I am a lone monk walking through the world with a leaky umbrella..."* Unfortunately, what Mao intended was something quite different: *"I am above the law, defying the powers of heaven".*

The two phrases are homonymous in Chinese. Clearly, language has not been perfectly designed for communication. But that is part of its mystery, and a reason for our infinite curiosity concerning its origins and development.

References

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