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Regularization of languages by adults and children: A mathematical framework

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ABSTRACT

The fascinating ability of humans to modify the linguistic input and "create" a language has been widely discussed. In the work of Newport and colleagues, it has been demonstrated that both children and adults have some ability to process inconsistent linguistic input and "improve" it by making it more consistent. In Hudson Kam and Newport (2009), artificial miniature language acquisition from an inconsistent source was studied. It was shown that (i) children are better at language regularization than adults and that (ii) adults can also regularize, depending on the structure of the input. In this paper we create a learning algorithm of the reinforcement-learning type, which exhibits patterns reported in Hudson Kam and Newport (2009) and suggests a way to explain them. It turns out that in order to capture the differences between children's and adults' learning patterns, we need to introduce a certain asymmetry in the learning algorithm. Namely, we have to assume that the reaction of the learners differs depending on whether or not the source's input coincides with the learner's internal hypothesis. We interpret this result in the context of a different reaction of children and adults to implicit, expectation-based evidence, positive or negative. We propose that a possible mechanism that contributes to the children's ability to regularize an inconsistent input is related to their heightened sensitivity to positive evidence rather than the (implicit) negative evidence. In our model, regularization comes naturally as a consequence of a stronger reaction of the children to evidence supporting their preferred hypothesis. In adults, their ability to adequately process implicit negative evidence prevents them from regularizing the inconsistent input, resulting in a weaker degree of regularization.

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1. Introduction

Natural languages evolve over time. Every generation of speakers introduces incremental differences in their native language. Sometimes such gradual slow change gives way to an abrupt movement when certain patterns in the language of the parents differ significantly from those in the language of the children. The fascinating ability of humans to modify the linguistic input and "create" a language has been widely discussed. One example is the creation of the Nicaraguan Sign Language by children in the course of only several years (Senghas, 1995; Senghas & Coppola, 2001; Senghas, Coppola, Newport, & Supalla, 1997). Other examples come from the creolization of pidgin languages (Andersen, 1983; Sebba, 1997; Thomason & Kaufman, 1991). It has been documented that in the time-scale of a generation, a rapid linguistic change occurs that creates a language from something that is less than a language (a limited pidgin language (Johnson, Shenkman, Newport, & Medin, 1996), or a collection of home-signing systems in the example of the Nicaraguan Sign Language).

Language regularization has been extensively studied in children, see e.g. work on the phenomenon of over-regularization in children (Marcus et al., 1992). Goldin-Meadow, Mylander, de Villiers, Bates, and Volterra (1984), Goldin-Meadow (2005), and Coppola and Newport (2005) studied deaf children who received no conventional linguistic input, and found that their personal communication systems exhibited a high degree of regularity and language-like structure. The ability of adult learners to regularize has also been discussed (Bybee & Slobin, 1982; Cochran, McDonald, & Parault, 1999; Klein & Perdue, 1993).

Much attention in the literature is paid to statistical aspects of learning, showing that learners are able to extract a number of statistics from linguistic input with probabilistic variation (Gómez & Gerken, 2000; Griffiths, Chater, Kemp, Perfors, & Tenenbaum, 2010; Saffran, 2003; Wonnacott, Newport, & Tanenhaus, 2008). Identifying statistical regularities and extracting the underlying grammatical structure both seem to contribute to human language acquisition (Seidenberg, MacDonald, & Saffran, 2002).

Reali and Griffiths (2009) demonstrated that in the course of several generations of learning, the speakers shift from a highly inconsistent, probabilistic language to a regularized, deterministic language. A mathematical description of this phenomenon was presented based on a Bayesian model for frequency estimation. This model demonstrated, much like in experimental studies, that while in the course of a single "generation" no bias toward regularization was observed, this bias became apparent after several generations. The same phenomenon was observed by Smith and Wonnacott (2010). It was suggested that gradual, cumulative population-level processes are responsible for language regularity.

In this paper we focus on a slightly different phenomenon. The work of Elissa Newport and colleagues demonstrates that language regularization can also happen within one generation. A famous example is a deaf boy Simon (see Singleton & Newport (2004)) who received all of his linguistic input from his parents, who were not fluent in American Sign Language (ASL). Simon managed to improve on this inconsistent input and master the language nearly at the level of other children who learned ASL from a consistent source (e.g. parents, teachers, and peers fluent in ASL). Thus he managed to surpass his parents by a large margin, suggesting the existence of some innate tendency to regularization.

The work of Newport and her colleagues sheds light into this interesting phenomenon. In a number of studies, it has been demonstrated that both children and adults have the ability to process inconsistent linguistic input and "improve" it by making it more consistent. When talking about the usage of a particular rule, this ability was termed "frequency boosting," as opposed to "frequency matching." Let us suppose that the "teacher" (or the source of the linguistic input) is inconsistent, such that it probabilistically uses several forms of a certain rule. Frequency boosting is the ability of a language learner to increase the frequency of usage of a particular form compared to the source. Frequency matching happens when the learner reproduces the same frequency of usage as the source. Hudson Kam and Newport (2005) and Hudson Kam and Newport (2009) showed that (i) children are better at frequency boosting than adults and that (ii) adults can also frequency boost, depending on the structure of the input.