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RULE LEARNING IN HUMANS AND ANIMALS

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In recent years, artificial language learning experiments have revealed a rich and complex picture of the abilities of different species and different human age groups to discover simple patterns in sequences. In one influential study, Aslin et al. (1998) show that human infants use transitional probabilities (TP's), and not just co-occurrence frequencies, between adjacent syllables in a monotonous stream of speech to segment it into word-like units.

Peña et al. (2002) presented human adults with a sequence of syllables composed of concatenated triplets of the form AXC, where A and C consistently co-occur, while X may vary. Tested for recognition after 100 exposures to the sequence, their subjects show no preference for either rule-following unattested sequences (AYC, with Y unobserved in that position; henceforth 'rule-words') or rule-breaking attested sequences (XCA or CAX, henceforth 'part-words'). After 300 exposures, however, subjects prefer part-words (*time effect)*, while with merely 20 exposures but with subliminal pauses added between triplets, subjects prefer rule-words (*micropause effect*). These results are often interpreted as evidence for two different processes: a statistical mechanism that tracks transitional probabilities, and a rule mechanism for structure detection. Endress and Bonnatti (2006) emphasize that the time effect runs contrary to the prediction of single mechanism models, and thus supports their More-than-One-Mechanism (MoM) hypothesis.

Toro and Trobalón (2005) perform similar experiments with rats, and report a number of qualitative differences with the human results. In particular, although the rats learn to discriminate between stimuli on the basis of co-occurrence frequencies, T&T report that they find no TP-effect and no rule learning (and hence no time effect and no micropause effect).

In our work, we investigate through modelling whether the presented empirical results really rule out a single mechanism account for the results on humans as well as rodents. We define a probabilistic model which uses the Simple Good-Turing method to quantify a subject's *willingness to generalize* as the amount of probability mass that is reserved for unobserved sequences. We further model the probability that a subject will retain a particular subsequence ($P_{ret}(s) = A^{length(s)}$) or recognize it and hence increase its subjective count ($P_{rec}(s) = (1 - B^{activation(s)})D^{\#types}$) .

The model involves three free parameters (A, B, and D, all between 0 and 1) that determine memory constraints and may be fitted to the empirical data. The retention probability is inversely correlated with the length of the subsequence. The probability for recognition uses an activation function that depends on the accumulated subjective frequency of the subsequence. The number of word types adds difficulty to the task, resulting in a decreased recognition probability.

The predictions of the model are summarized below. Figure 1 shows that for a broad range of parameter settings the willingness to generalize decreases over time. In figure 2, we illustrate for one arbitrary parameter setting that the difference between the proportion of words and that of part-words in memory becomes smaller with time.

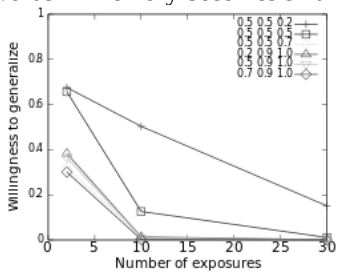

Figure 1. Willingness to generalize.

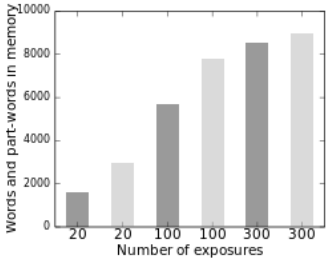

Figure 2: Dark grey: words; light grey: part-words.

The two graphs demonstrate different effects on the preference for rule-words over part-words: the willingness to generalize decreases over time (favouring part-words), while the gap between relative subjective frequencies of part-words and words decreases. The interplay between the two effects can yield a time effect as Peña et al. report for humans, but also a complete rejection of novel strings as T&T report, depending on the choice of parameters. Although specific predictions from this model can only be worked out when we will fit it to the raw data, we can already conclude that the claims about multiple mechanisms in humans and the lack of a rule-learning ability in rats are premature. The behavioural difference between humans and rats can thus be accounted for with different values of the parameters of a shared system for pattern recognition. Our work also demonstrates the usefulness of developing models of artificial language learning in multiple species, and its potential for improving our understanding of the biological basis of language.

Aslin, R., Saffran, J., & Newport, E. (1998). Computation of conditional probability statistics by 8-month-old infants. *Psych. science*, *9*(4), 321-324.

Endress, A., & Bonatti, L. (2007). Rapid learning of syllable classes from a perceptually continuous speech stream. *Cognition*, *105*(2), 247-299.

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