Mirror recursion learning in the Box Prediction artificial grammar paradigm

Whitney Tabor, Pyeong Whan Cho, & Emily Szkudlarek (University of Connecticut & Haskins Laboratories)
whitney.tabor@uconn.edu

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Recursion is widely regarded as a core feature of human language processing [1][2] although there is debate about whether it is universal [3], and whether a symbolic or a recurrent connectionist encoding [4] underlies this feature. Because forms of recursion vary across languages, learners must discover specific recursive structures via experience. We explore recursion learning in an artificial grammar paradigm, and offer evidence that (a) a small percentage of undergraduate students can discover mirror recursion, not merely counting recursion, in the laboratory and (b) the learning process involves mastering the timing of syntactic gestures, in line with the connectionist view.

Counting recursion (e.g. ab, aabb, aaabbb,…) can be identified by a mechanism that merely counts symbols. *Mirror recursion* (e.g., Grammar 1) requires keeping track of symbol order, not merely counting. Most natural language recursion is mirror recursion [5]. Although several artificial grammar studies demonstrate recursion learning by both humans (e.g., [6]) and animals ([7]), these have been criticized as not relevant to natural language because the evidence only supports counting recursion (e.g., [8]). We extend [9]'s new evidence for artificial mirror recursion learning with a "Box Prediction" paradigm, permitting detailed monitoring of the emergence of recursive structure.

Sentences were generated by Grammar 1 and strung end to end in a sequence of 553 words. Early in the sequence, Level 1 sentences (abp, xyp) were most common, but over the first 410 words (the "Training Phase"), Level 2 sentences (aabbp, axybp, xabyp, xxyyp) became increasingly common. The last 143 trials (the "Test Phase") included 4 Level 3 types (aaabbbp, axxyybp, aaxybbp, xaabbyp). Grammar learning was operationalized via five black boxes on a computer screen. When the participant clicked a box, one box changed color, specified by the sequence just described. The participant had to predict (by clicking on it) the unique box that would change color at each time step. Predictions: (a) We expected some participants to generalize to Level 3 sentences on the basis of exposure to Levels 1 and 2 only. (b) We expected temporal variability to decrease as learning progressed.

Results: Of 71 undergraduates, 12 scored over 80% in the last 100 training trials, suggesting that they were approximating at least a Level 1-2 finite state grammar. Of these 12, the two top scorers generalized perfectly to each first instance of the four Level 3 types at test. If, contrary to hypothesis (a), all 12 were using finite state encodings, and they guessed randomly on novel transitions, the chances of observing 2 or more perfect scorers would be 0.9% ($p = .009$). We infer that these two discovered mirror recursion. Fitting a temporal variability parameter to a model of each participant who significantly improved indicated that the temporal variability of predictions decreased in the later stages of learning, supporting the gestural timing claim (b). We conclude that mirror recursion can occur in the laboratory, that our method gives helpfully detailed information about the learning process, and that variability in the timing of syntactic gestures deserves further attention.

Grammar 1: $R \rightarrow S\ p$, $S \rightarrow a\ S\ b$, $S \rightarrow x\ S\ y$, $S \rightarrow 0$. E.g., abp, xyp, aabbp, axybp,…

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