

# Recursion, Language, and Starlings

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## Abstract

It has been claimed that recursion is one of the properties that distinguishes human language from any other form of animal communication. Contrary to this claim, a recent study purports to demonstrate center-embedded recursion in starlings. I show that the performance of the birds in this study can be explained by a counting strategy, without any appreciation of center-embedding. To demonstrate that birds understand center-embedding of sequences of the form  $A^n B^n$  (such as  $A_1 A_2 B_2 B_1$ , or  $A_3 A_4 A_5 B_5 B_4 B_3$ ) would require not only that they discriminate such patterns from other patterns, but that they appreciate that elements must be bound from the outside in (thus, in the above examples,  $A_1 B_1$ ,  $A_2 B_2$ ,  $A_3 B_3$ ,  $A_4 B_4$ ,  $A_5 B_5$  are bound pairs). This has not been shown in nonhuman species, and sentences with this structure are difficult even for humans to parse. There appears to be no evidence to date that nonhuman species understand recursion.

*Keywords:* Language; Recursion; Animal communication; Center-embedding

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## 1. Introduction

Hauser, Fitch, and Chomsky (2000) have distinguished between the faculty of language in the broad sense (FLB), which is shared between humans and other species, and the faculty of language in the narrow sense (FLN), which is uniquely human. The minimum characteristic that distinguishes FLN from FLB, they claim, is recursion. Pinker and Jackendoff (2005) refer to this as the “recursion-only claim,” and have argued that there are other, non-recursive aspects of human language that distinguish it from other forms of animal communication. Nevertheless it seems clear that recursion is at least one of the distinguishing attributes of human language, which raises the challenge of showing that some nonhuman species may be capable of producing or parsing recursive sequences.

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In this article I examine two recent attempts to demonstrate recursive parsing in nonhuman species, one by Hauser and Fitch (2004) in tamarins, and the other by Gentner, Fenn, Margoliash, and Nusbaum (2006) in starlings (*Sturnus vulgaris*). Before doing so, I consider the nature of recursion.

## 2. What is recursion?

Recursion is a computational procedure that calls itself, or that calls an equivalent kind of procedure. A distinction can be drawn between *tail recursion* and *center-embedded recursion*. In tail recursion, the procedure is invoked at the end of a sequence, as in the familiar story of *The House the Jack Built*:

This is the house that Jack built.

This is the malt that lay in the house that Jack built.

This is the rat that ate the malt that lay in the house that Jack built.

This is the cat that worried the rat that ate the malt that lay in the house that Jack built.

In each sentence a constituent from the previous sentence is added to the end. As young children quickly understand, this recursive procedure allows us to create sentences of any desired length and complexity.

At one level, tail recursion is simply iteration. That is, a child may keep adding constituents to a sentence while forgetting previous constituents. Nevertheless understanding of iterative sentence like those above may depend on preservation of all constituents in encoding or decoding the sentence. In the fourth sentence, for example, only one cat will do, namely, the cat that worried the rat that ate the malt, etc. In short, all constituents are necessary for full meaning, and the various constituents cannot be construed as unrelated. Nevertheless iterated or repeated sequences are a common feature of both primate and bird calls, whatever they might mean, so iteration at this level is not a satisfactory measure of the uniqueness of human language.

More critical is so-called center-embedded recursion, in which the procedure invokes an instance of itself or of an equivalent procedure in the middle of the computation. The added complication here is that the procedure must resume from where it left off. This requires a memory device, such as a stack of pointers, indicating where to pick up the procedure once an embedded constituent has been completed. Center-embedded recursion can be illustrated with reference to the sentences in *The House That Jack Built* with the following example:

The malt that the rat ate lay in the house that Jack built.

The malt that the rat that the cat killed ate lay in the house that Jack built.

In the first of these examples, the phrase *that the rat ate* is embedded in the sentence *The malt lay in the house that Jack built*, while in the second the phrase *that the cat killed* is embedded in the phrase *that the rat ate*. As the second example illustrates, more than one level

of embedding can be difficult even for humans to parse, and occur with very low frequency in natural discourse.

### 3. Testing recursion in nonhuman species

Nevertheless, it was center-embedded recursion that both Fitch and Hauser (2004), working with tamarins, and Gentner et al. (2006), working with starlings, elected to test. Center-embedded recursion can also be considered an example of context-free grammar (CFG), as distinct from a finite-state grammar (FSG), in which the constituents are fully specified by transitional probabilities between them. CFG cannot be so specified, but is typically specified by rewrite rules involving recursive elements (Chomsky, 1957).

In both studies, two classes of sounds were identified, and labeled A and B. In the study by Fitch and Hauser (2004) on tamarins, the sounds were eight consonant-vowel syllables spoken by a male voice (A syllables) or by a female voice (B syllables). In the study by Gentner et al. (2006) on starlings, the A sounds were rattles and the B sounds were warbles, and there were again eight possibilities within each category, chosen from the repertoire of a single male starling. Sequences in which the A and B sounds simply alternate, as in  $A_i B_j A_k B_l$ , follow a FSG of the form  $(AB)^n$ , whereas those in which a sequence of As is followed by a sequence of Bs, as in  $A_i A_j B_k B_l$ , follow a CFG of the form  $A^n B^n$ . Specific instances of A and B sounds were varied so that the animals could not rely on memory for particular sequences. Fitch and Hauser found that tamarins had little difficulty distinguishing the FSG sequences, but could not master the CFG sequences, where  $n$  was either 2 or 3. They concluded that tamarins were therefore unable to process recursive sequences.

More provocatively, Gentner et al. (2006) found that starlings could discriminate both kinds of sequences even up to an  $n$  of 4, although a great many trials were required to achieve the CFG discriminations. They began by training 11 birds to discriminate  $(AB)^2$  sequences from  $A^2 B^2$  sequences, choosing 16 specific sequences, eight from each grammar, from the total number of possible sequences. Half of the birds were taught to respond to the  $(AB)^2$  sequences by pecking a key and withhold response to the  $A^2 B^2$  sequences, and half were taught the reverse discrimination.<sup>1</sup> Nine of the 11 birds reached a criterion of  $d' > 1.0$ , with a 95% confidence interval above zero, after a mean of 30,344 trials, which the authors describe as slow by the usual standards of song-recognition learning in birds. The first four birds to reach stable acquisition performance were then tested on novel sequences conforming to the same grammars (i.e.,  $(AB)^2$  and  $A^2 B^2$ ) and correctly classified them at well above a chance level, implying that they had not learned the specific sequences, but had instead learned general knowledge of the grammars.

To check that they had not simply learned the FSG and treated the CFG as the complement, the birds were next given 16 agrammatic patterns based on the sequences AAAA, BBBB, ABBA, and BAAB, with four exemplars of each, along with new  $(AB)^2$  and  $A^2 B^2$  sequences as probes. All four birds significantly discriminated the  $(AB)^2$  sequences from the agrammatic sequences, and three of the four discriminated the  $A^2 B^2$  from the agrammatic ones. These three birds therefore seemed to have learned both FSG and CFG patterning rules. This was followed by probes of  $(AB)^n$  and  $A^n B^n$  sequences for  $n = 3$  and  $n = 4$ , while maintaining

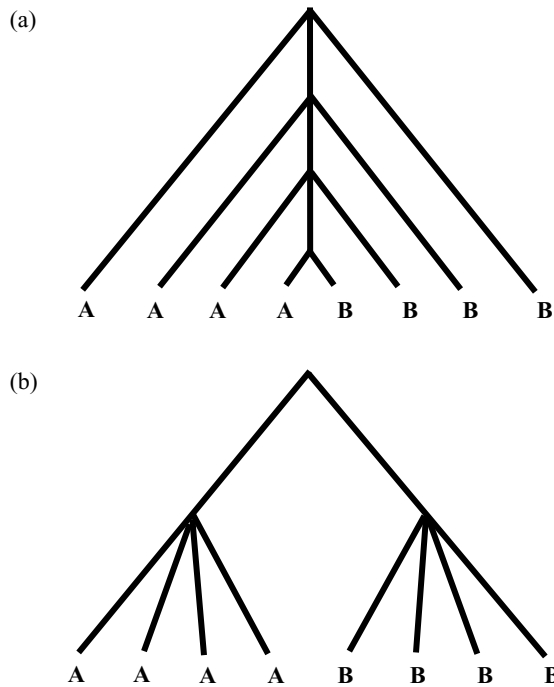


Fig. 1. Tree structure for (a) center-embedded recursion, and (b) double iteration.

baseline performance with  $n = 2$ . Performance remained above chance, suggesting that the birds generalized to higher-order sequences.

Gentner et al. carried out further tests to rule out other possibilities. The birds discriminated the grammatical sequences from the combinations  $A^1B^3$ ,  $A^3B^1$ ,  $A^2B^3$ , and  $A^3B^2$ . They were able to rule out the possibility that they simply checked for B/A transitions ( $A^nB^n$  sequences have none) or for AA or BB pairs, or that they based the discriminations on initial or final pairs. The experiment therefore seems to have convincingly demonstrated that a subsample, at least, of the starlings based the discrimination on genuine understanding of rules governing  $(AB)^n$  and  $A^nB^n$  sequences, generalized over values of  $n$  from 2 to 4, and over different selections of A (rattles) and B (warbles).

Gentner et al. conclude that the discrimination of the  $A^nB^n$  sequences demonstrates ability to parse sequences according to a CFG. They point out that a FSG for  $A^nB^n$  could account for the discrimination, but would require 13 production rules, making such a solution unlikely. The question, though, is whether the birds understood the  $A^nB^n$  sequences as following a center-embedded recursive rule, as shown diagrammatically in Fig. 1a, or whether they adopted a simpler rule.

#### 4. Alternative parsing

A simpler structure is shown in Fig. 1b. This structure represents the  $A^nB^n$  sequences as double iterations, with no center-embedding. To decide whether a given sequence obeys

the rule, the birds need simply count the number of successive As, and then the number of successive Bs, and accept the sequence as belonging to  $A^nB^n$  if the numbers are equal. This structure does not conform to a FSG, but does not involve center-embedded recursion, and does not require place-holders. However it does require a counting mechanism, and memory for the number of elements.

The question then is how the birds decided whether the runs of As and Bs in  $A^nB^n$  were of the same length, implying an ability to count, or at least to match quantities. Gentner et al. seem to recognize counting as at least a possibility when they suggest, but rule out, the possibility that the birds may have been counting B-to-A transitions. Nevertheless, to match sequence lengths, as in Fig. 1b, need not have required counting in the strict sense; a simpler mechanism such as subitization (Kaufman, Lord, Reese, & Volkman, 1949) may have been sufficient. Sensitivity to numerosity has been demonstrated in a wide variety of species, including chimpanzees (Beran, 2001), orangutans (Shumaker, Palkovich, Beck, Guagnano, & Morowitz, 2001), monkeys (Brannon & Terrace, 2000; Judge, Evans & Vyas, 2005), dolphins (Kilian, Yaman, von Fersen, & Gunturkun, 2003), lions (McComb, Packer, & Pusey, 1994), pigeons (Rilling, 1967; Olthof & Roberts, 2000; Xia, Emmerton, Siemann & Delius, 2001), crows (Thompson, 1968), and coots (Lyon, 2003). Songbirds such as starlings are specialists in the production of repetitive sequences, and number perception for auditory sequences in birds may surpass that in humans (Thompson, 1969).

An African gray parrot appears able to count up to six, and having to learn to count a particular set of objects can readily transfer to new sets (Pepperberg, 1994, 2005). In the study by Gentner et al. the number to be counted (or subitized) did not exceed four—which is the approximate upper limit of subitization in humans (Kaufman et al., 1949). Since the discrimination between sequences, although better than chance, was not perfect, the birds may indeed have been using subitization rather than true counting. It is also possible that matching was based on simple estimation of duration.

Whether or not the starlings parsed the  $A^nB^n$  sequences by number estimation, they are known to be sensitive to the patterning of sequences. For example, Braaten and Hulse (1993) taught starlings to discriminate two sequences of artificial sounds, 11111000 and 01010011, presented in continuous cycles. The birds accomplished the discrimination regardless of the starting point in the cycle, and two of four birds maintained the discrimination when the sounds were replaced by two new sounds, and even when the original sounds were reversed. This suggests that the birds in the study by Gentner et al. may have based the discrimination of  $A^nB^n$  sequences on a pattern template, without any sense of center-embedding, or indeed of any “grammatical” rule used to create the sequences.

As pointed out above, center-embedding can be difficult even for humans, and close to impossible when  $n$  is as high as four. A sentence like *The man that the cat that the dog that the children loved chased scratched slept*, though grammatically correct, takes some considerable effort to unpack. In a more primitive language consisting of only nouns and verbs, it might be reduced to the form  $A^4B^4$ : *Man cat dog children loved chased scratched slept*.

These considerations call into question that the starlings in the study by Gentner et al. (2006) parsed the  $A^nB^n$  sequences in terms of center-embedding. It is much more likely that they used a simple strategy such as counting or subitizing the numbers of As and Bs, and

then matching them. This strategy has no obvious counterpart in human language, but seems a natural strategy in classifying strings of nonlinguistic elements.

## 5. How to demonstrate true recursion

To demonstrate true center-embedding, one would need to show not only that center-embedded sequences can be discriminated from those not obeying the rule, but also that the pairs are matched, from the outside pairs inwards. That is, if the sequences are to be interpreted as constituents embedded in constituents, the constituents themselves must have some integrity. For example, in the sentence *The man that the cat that the dog that the children loved chased scratched slept*, the speaker or the listener needs to understand that it was the man who slept, the cat that scratched, the dog that chased, and the children who loved. Such parsing might perhaps be tested in an animal with at least some ability to construct meaningful noun-verb pairs. For example, the bonobo Kanzi is said to have reasonable comprehension of spoken sentences such as *Take the ball to the bedroom*, or *Make the doggie bite the ball* (Savage-Rumbaugh, Shanker, & Taylor, 1998). The question is whether Kanzi might understand sentences where a phrase is embedded, such as *Take the ball that is on the potty to the bedroom*. Assuming that Kanzi's response is based on the key words *take*, *ball*, *potty*, and *bedroom*, the question would be whether he produces the correct sequence, rather than, say, taking the ball in the bedroom to the potty, or even taking the potty to the ball in the bedroom. One problem here, though, is that the English sentence includes further information as to the phrase structure; such as the word *that*, as well as other function words (*on*, *to*) that help disambiguate the meaning. The sequence *take ball potty bedroom* is ambiguous, unless there are phrase markers. My guess is that center-embedding will prove impossible for Kanzi, but the challenge is there.

An alternative nonlinguistic approach, perhaps appropriate for further testing with the starlings, might be to establish connections between AB pairs, and then test whether the birds can still recognize pairings when other pairs are nested within them. For example, if  $A_i B_i$  are pairs for all  $i$ , then sequences like  $A_i A_j B_j B_i$ , or  $A_i A_j A_k B_k B_j B_i$  obey the rule, whereas any other combinations do not. Such discriminations would fail if the starlings depended on a counting strategy of the sort outlined earlier.

## 6. Conclusions

There is as yet no irrefutable evidence for recursion in the processing of sequences in any species other than humans. The studies of tamarins by Fitch and Hauser (2004) and of starlings by Gentner et al. (2006) do not provide sufficient tests of center-embedded recursion, despite the authors' claims. Where animals can make the discriminations between  $A^n B^n$  sequences and those that do not obey this formula, the discrimination is more likely to be based on a counting or subitizing mechanism than on center-embedding. To demonstrate parsing of  $A^n B^n$  sequences based on center-embedded recursion, it would be necessary to show that elements are "bound" from the outside in, such that the outermost elements are correctly associated, the next-to-outermost elements correctly associated, and so on.

The article by Gentner et al. does demonstrate the ability of starlings to discriminate sequences based on a CFG, but does not necessarily demonstrate any understanding of the recursive nature of center-embedded sequences. There are considerable challenges to be met in order to demonstrate true center-embedding, whether in the context of animal protolanguage or nonlinguistic sequential calls. For the present, at least, there is no convincing evidence that any nonhuman species is truly capable of recursive syntactic parsing.

## Notes

1. It is not made clear how the sample of 11 birds was divided into halves.

## References

- Beran, M. J. (2001). Summation and numerosness judgments of sequentially presented sets of items by chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology*, *115*, 181–191.
- Braaten, R. F., & Hulse, S. H. (1993). Perceptual organization of auditory temporal patterns in European starlings (*Sturmus vulgaris*). *Perception & Psychophysics*, *54*, 567–578.
- Brannon, E. M., & Terrace, H. S. (2000). Representation of the numerosities 1–9 by rhesus macaques. *Journal of Experimental Psychology: Animal Behavior Processes*, *26*, 31–49.
- Chomsky, N. (1957). *Syntactic structures*. The Hague: Mouton.
- Fitch, W. T., & Hauser, M. D. (2004). Computational constraints on syntactic processing in a nonhuman primate. *Science*, *303*, 377–380.
- Gentner, T. Q., Fenn, K. M., Margoliash, D., & Nusbaum, H. C. (2006). Recursive syntactic pattern learning by songbirds. *Nature*, *440*, 1204–1207.
- Hauser, M. D., Fitch, W. T., & Chomsky, N. (2002). The faculty of language: What is it, who has it, and how did it evolve? *Science*, *298*, 1569–1579.
- Judge, P. G., Evans, T. A., & Vyas, D. K. (2005). Ordinal representation of numeric quantities by brown capuchin monkeys (*Cebus paella*). *Journal of Experimental Psychology: Animal Behavior Processes*, *31*, 79–94.
- Kaufman, E. L., Lord, M. W., Reese, T. W., & Volkman, J. (1949). The discrimination of visual number. *American Journal of Psychology*, *62*, 498–525.
- Kilian, A., Yaman, S., von Fersen, L., & Gunturkun, O. (2003). A bottle-nosed dolphin discriminates visual stimuli differing in numerosity. *Learning & Behavior*, *31*, 133–142.
- Lyon, B. E. (2003). Egg recognition and counting reduce costs of avian conspecific brood parasitism. *Nature*, *422*, 495–499.
- McComb, K., Packer, C., & Pusey, A. (1994). Roaring and numerical assessment in contests between groups of female lions, *Pantera leo*. *Animal Behaviour*, *47*, 379–387.
- Olthof, A., & Roberts, W. A. (2000). Summation of symbols by pigeons (*Columbia livia*): the importance of number and mass of reward items. *Journal of Comparative Psychology*, *114*, 158–166.
- Pepperberg, I. M. (1994). Evidence for numerical competence in an African grey parrot (*Psittacus erithacus*). *Journal of Comparative Psychology*, *108*, 36–44.
- Pepperberg, I. M., & Gordon, J. D. (2005). Number comprehension by a grey parrot (*Psittacus erithacus*), including a zero-like concept. *Journal of Comparative Psychology*, *119*, 197–309.
- Pinker, S., & Jackendoff, R. (2005). The faculty of language: What's special about it? *Cognition*, *95*, 201–236.
- Rilling, M. (1967). Number of responses as a stimulus in fixed interval and fixed ratio schedules. *Journal of Comparative & Physiological Psychology*, *63*, 60–65.
- Savage-Rumbaugh, S., Shanker, S.G., & Taylor, T. J. (1998). *Apes, language, and the human mind*. New York: Oxford University Press.

- Shumaker, R. W., Palkovich, A. M., Beck, B. B., Guagnano, G. A., & Morowitz, H. (2001). Spontaneous use of magnitude discrimination and ordination by the orangutan (*Pongo pygmaeus*). *Journal of Comparative Psychology*, *115*, 385–391.
- Thompson, N. S. (1968). Counting and communication in crows. *Communications in Behavioural Biology*, *2*, 223–225.
- Thompson, N. S. (1969). Individual identification and temporal patterning in the cawing of common crows. *Communications in Behavioral Biology*, *4*, 29–33.
- Xia, L., Emmerton, J., Siemann, M., & Delius, J. D. (2001). Pigeons (*Columbia livia*) learn to link numerosities with symbols. *Journal of Comparative Psychology*, *115*, 83–91.