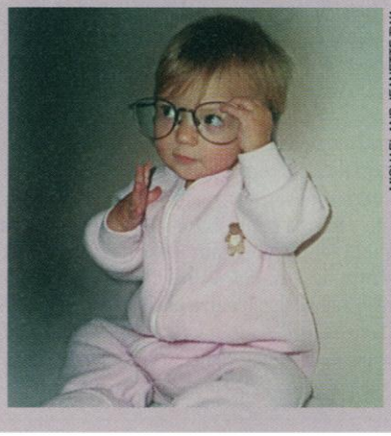
LETTERS

Little statisticians?

How human infants might learn the components of language, and what recent research results mean in light of Noam Chomsky's theories about language acquisition, are debated. And readers continue to express their concern about "misplaced" crabs, along with a plant that is not a grass.



MICHAEL AND JEANETTE TWA

Acquiring Language

The report "Statistical learning by 8-month-old infants" by Jenny R. Saffran *et al.* (13 Dec., p. 1926) shows that, after listening to 2-minute strings of three-syllable nonsense "words," infants listened longer to stimuli that did not contain these words than they did to strings that did contain these words.

In the accompanying Perspective "Learning rediscovered" (p. 1849), Elizabeth Bates and Jeffrey Elman state that this report is important because the results "fly in the face of received wisdom" by showing that "babies can learn." But the appearance of a refutation—indeed, the appearance of a controversy—arises only from Bates and Elman's inaccurate characterization of views with which they purport to disagree. Their discussion does not distinguish two senses of the term "learning" and consequently blurs two logically distinct issues.

The first issue concerns the division of labor between innate and environmental factors in language acquisition. The existence of specific biological support for language is beyond doubt. Arguments come from the nature of structural properties common to all languages, restrictions on the degree to which languages vary, and linguistic knowledge not attributable to the environment, as well as uniform patterns of normal and abnormal language development—plus the fact that nonhuman mammals with good statistical learning and computational capacities (*1*) nevertheless do not develop language. These observations are compatible with the results of Saffran *et al.* No matter how rich a child's innate linguistic endowment, the fact that she acquires the language of her community tells us that she also has methods for analyzing input. No "received wisdom" has ever doubted the existence of "learning" in this nontechnical sense (*2*).

A second and different issue is the domain-specificity of cognitive functions. Some researchers have indeed questioned whether humans possess "generalized" learning mechanisms not associated with particular cognitive domains. In discussing this topic, Chomsky (*3*) and others (*4*) use the term "learning" in a technical sense to refer to generalized mechanisms of this sort. In their Perspective, Bates and Elman assert that Saffran *et al.*'s results support the existence of this "powerful" type of "learning," even calling that the "central contribution of the Saffran *et al.* report." But, as Saffran *et al.* themselves note, their study makes no such contribution. Because their work involved only linguistic stimuli, it tells us nothing about other cognitive domains, but speaks to the question of "learning" only in the nontechnical sense.

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References

1. C. R. Gallistel, *The Organization of Learning* (Massachusetts Institute of Technology Press, Cambridge, MA, 1990).
2. K. Wexler, *Dev. Psychobiol.* **23**, 645 (1990).
3. N. Chomsky, *Rules and Representations* (Columbia Univ. Press, New York, 1980).
4. M. Piatelli-Palmarini, *Cognition* **31**, 1 (1989).

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That infants learn words by remembering sequences of sounds is not new or controversial (*1*). What is the alternative? That English words are in American babies' genes, Japanese words in Japanese babies' genes, and so on? No one believes that, including Noam Chomsky, whose quotations were reproduced in the Perspective by Bates and Elman. Surely, when Chomsky said that "learning" is a misleading term, he was not suggesting that English is in the genes; and if he were, Saffran *et al.*'s results would hardly be needed to refute him.

Saffran *et al.* and Bates and Elman suggest that if children can learn words by recording frequent sound sequences, they might learn grammar the same way. But words and grammar are different. The sequence of sounds making up a word is not capturable by rules ("monkey" cannot be understood as a combination of "mon" and "key"), but must be memorized. And because there are a finite number of words, they all can be recorded.

The sequence of words making up a sentence, however, *is* capturable by rules. (For example, "the eggplant ate Chicago," though an improbable word sequence, can be understood from the meanings of "eggplant," "ate," and "Chicago" and the way they are combined). Word sequences need not and cannot be memorized, because they form an open-ended set. Moreover, grammar does not merely sequence words, but relates each sequence to a meaning through hierarchical, cross-referenced data structures.

Learning words and learning grammar are thus different computational problems. The statistical learning procedures that have been applied to grammar do not behave even remotely like people, but instead guess the next word of a string in a highly simplified artificial language, rather than converting meanings to real sentences and vice versa. Realistic models of human language have all required algorithms designed to process combinatorial rules and hierarchical meaning structures.

The contrast made by Saffran *et al.* between "learning" and "innate factors" is a poor basis for understanding a process as complex as language acquisition. All parts of human psychology depend on experience, and learning always requires innate neural machinery to do the learning. Only by analyzing what exactly is learned, and what kinds of mechanisms are capable of learning it, can we make sense of the interesting data in the report by Saffran *et al.*

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References and Notes

1. For example, I have written, "Perhaps [word] segmentation . . . can be accomplished in part by a combination of stochastic methods that tabulate syllable transition probabilities" [S. Pinker, *Language Learnability and Language Development* (Harvard Univ. Press, Cambridge, 1984), p. 28].

In their Perspective, Bates and Elman assert that Saffran *et al.* "have proven that babies can learn" and that "Noam Chomsky, the founder of generative linguistics, has argued for 40 years that language is unlearnable." That "babies can learn" is not a theorem subject to proof, but a long-known and widely accepted empirical observation. *How* babies learn has been the subject of intense investigation (over the last 40 years) on universal and comparative grammar, language acquisition and perception, sign language, and creole language. Family and twin studies of agrammatism and expressive and receptive aphasias; studies of split-brain patients, linguistic savants, and language-isolated children; and research on the electrical activity of the brain have helped to shape the field (*1*). All of this work converges on the conclusion that hu-

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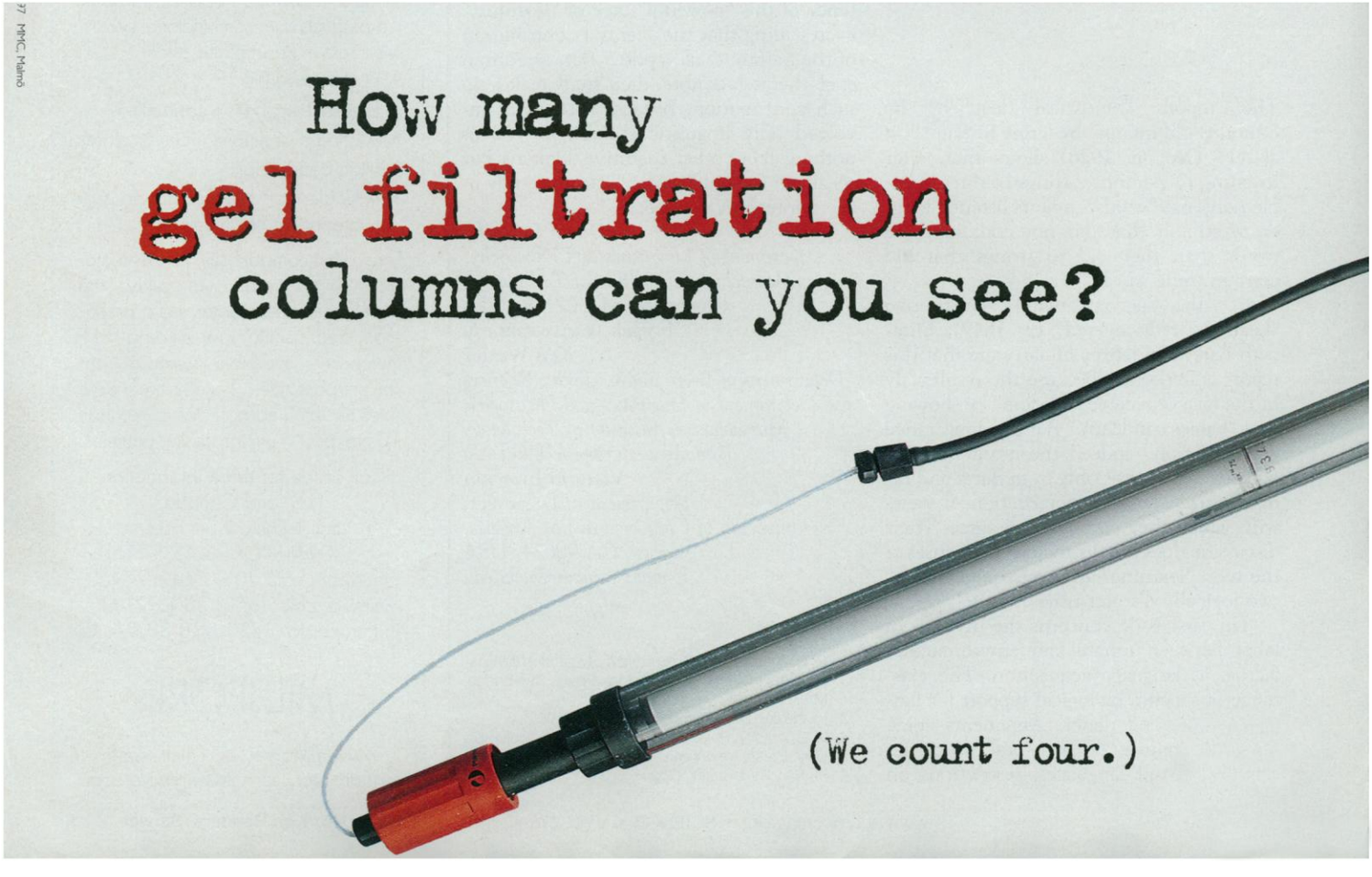

man language, like any other biological system, results from an interplay of genetic and environmental factors. The assertion by Bates and Elman that Chomsky argued that "language is unlearnable" misrepresents his work, which is apparent to the linguistics community, but perhaps not to the general reader.

Chomsky stated that a central task for the biology of language is to develop a "learning theory for humans in the domain [of] language" and has put forth a variety of proposals about this development process over the past 40 years (*2*). He went on to state that scientists might seek development theories for other cognitive domains for humans (or for other organisms, with their own special cognitive capacities), such as recognizing a face, determining the personality of other people, "recognizing a melody under transposition," and understanding spatial relations, for example.

Most researchers on the biology of language feel that the central question is how to tease apart the genetic and environmental factors that interact to give us the knowledge, acquisition, use, neurological basis, and evolution of human language. Saffran *et al.* made some substantive remarks about these matters. The exaggerated statements made by Bates and Elman, however, were not helpful.

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References

1. M. C. Corballis, *The Lopsided Ape* (Oxford Univ. Press, New York, 1991); S. Pinker, *The Language Instinct* (Morrow, New York, 1994); L. Jenkins, *Biolinguistics: The Unification Problem* (Cambridge Univ. Press, Cambridge, 1997).
2. N. Chomsky, *Rules and Representations* (Columbia Univ. Press, New York, 1980); *Powers and Prospects* (South End, Boston, MA, 1996).

Statistical learners can analyze a text based on a small set of words by first computing the conditional entropy (uncertainty) of points around each syllable and then associating word boundaries with points of high conditional entropy. The experiments by Saffran *et al.* present evidence that human infants are such statistical learners. What the experiments do *not* show is that a learner with no innate predispositions as to the nature of language could extract from the text alone the principle itself of assigning word boundaries according to conditional entropy. Rather, the learner must be built from the beginning to use such a procedure to discover linguistic units. This is the "poverty of the stimulus" argument. Language data do not come packaged with instructions for their own analysis; any effective learner must come to the data with prior constraints on its hypotheses. In this form, the "poverty of the stimulus" argument is equivalent to Gold's famous mathematical result (*1*), which Bates and Elman misinterpret in their Perspective. Gold showed that, for even simple classes of languages, no procedure (statistical or other) exists that could learn a language without nontrivial a priori assumptions.

In sum, a learning machine can only learn things that its structure permits it to learn; whether the learning is done by statistical means is entirely orthogonal to the question of innate structure. While much remains to be discovered about language acquisition and its relation to general learning procedures, the uncritical empiricism of Bates and Ellman does not advance our understanding of these matters.

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References

1. E. Gold, *Inf. Control* **16**, 447 (1967).

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Response: Cognitive science is at a turning point, and nowhere is this more apparent than in the study of language. Basic assumptions that have dominated the field for 40 years are being reexamined, and exciting alternatives are being developed.

All four letters assert in various ways that language *must* be biologically constrained, because only humans can do it. We agree, and have said so explicitly in our Perspective and elsewhere (*1*). The central debate in our field is not about innateness per se, it is about the nature of this ability. For 40 years, Chomsky and his followers have argued that language can only be acquired with special mechanisms that evolved for language alone (the Language Acquisition Device). We and others (*1*, *2*) have a different view: Language evolved through quantitative changes in social, perceptual, and cognitive abilities—including statistical learning—that exist in other species. These abilities have been recruited for language, but they continue to do nonlinguistic work (that is, they have kept their "day jobs"). Jenkins and Maxam suggest that we have misinterpreted Chomsky, who rejects learning only in a "technical" sense. But Chomsky has been quite consistent on this issue (*3*, p. 161)

> The evidence seems compelling, indeed overwhelming, that fundamental aspects of our mental and social life, including language, are determined as part of our biological endowment, not acquired by learning.

and (*3*, p. 4)

> Certain aspects of our knowledge and understanding are innate, part of our biological endowment, genetically determined, on a par with the elements of our common nature that cause us to grow arms and legs rather than wings.

The "technical" sense of learning that Chomsky rejects is the one that most laymen understand: The ability to acquire something new in many different domains. In our Perspective, we reviewed three lines of evidence suggesting that such multipurpose skills play a major role in language learning: (i) neural network simulations of language development, (ii) large computerized corpora of written and spoken language showing that the input to learners is much richer than previously believed, and (iii) demonstrations of the speed and power of statistical learning in human infants. As Saffran *et al.* stated in their report, their results alone are insufficient to overturn the traditional approach. Taken together, however, these lines of evidence suggest that Chomsky and his followers have underestimated the power of learning and thereby overestimated the need to build language-specific knowledge into the organism in advance. The goal of our Perspective was to place the report into this larger context, although we respect the right of Saffran *et al.* to see things differently.

In their defense of Chomsky's approach, the letter writers have taken contradictory positions. Pesetsky *et al.* argue that the study by Saffran *et al.* provides evidence in favor of domain-specific language abilities, because the stimuli that their infants learned so readily are language-like. In the same vein, Clark *et al.* assert that statistical information (for interpreting conditional entropy) could not be used in language without a language-specific predisposition to do so. But the data presented in the study by Saffran *et al.* resemble those from many other studies (with adults as well as children) involving nonlinguistic stimuli (*4*, *5*) and have been simulated by connectionist networks that are not language-specific. Pinker takes the opposite tack, arguing that statistical induction may work for some domains (including word learning), but cannot work for grammar. Other studies in humans and neural networks (*1*, *2*, *5*, *6*), however, demonstrate that statistical inferencing can be used to acquire grammar. Pinker (and Saffran *et al.* in their response) are critical of connectionist approaches to language. While we agree that this technology has far to go, we are optimistic about its present and its future. The enterprise is new, and it is too soon to declare failure or victory.

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References and Notes

1. J. Elman *et al.*, *Rethinking Innateness* (Massachusetts Institute of Technology Press, Cambridge, MA, 1996).
2. M. Seidenberg, *Science* **275**, 1599 (1997).
3. N. Chomsky, *Language and Problems of Knowledge: The Managua Lectures* (Massachusetts Institute of Technology Press, Cambridge, MA, 1988).
4. A. Cleermans, *Mechanisms of Implicit Learning* (Massachusetts Institute of Technology Press, Cambridge, MA, 1993).
5. M. Haith *et al.*, *The Development of Future-Oriented Processes* (Univ. of Chicago Press, Chicago, 1994).
6. L. Gerken and R. Gomez, paper presented at meeting of Society for Research in Child Development, Washington, DC, April 1997.
7. In our Perspective, the pages for the first quote of Chomsky's writing were given incorrectly as "pp. 138–139." The quote was taken from pages 39 and 245 of *Rules and Representations* (Columbia Univ. Press, New York, 1980).

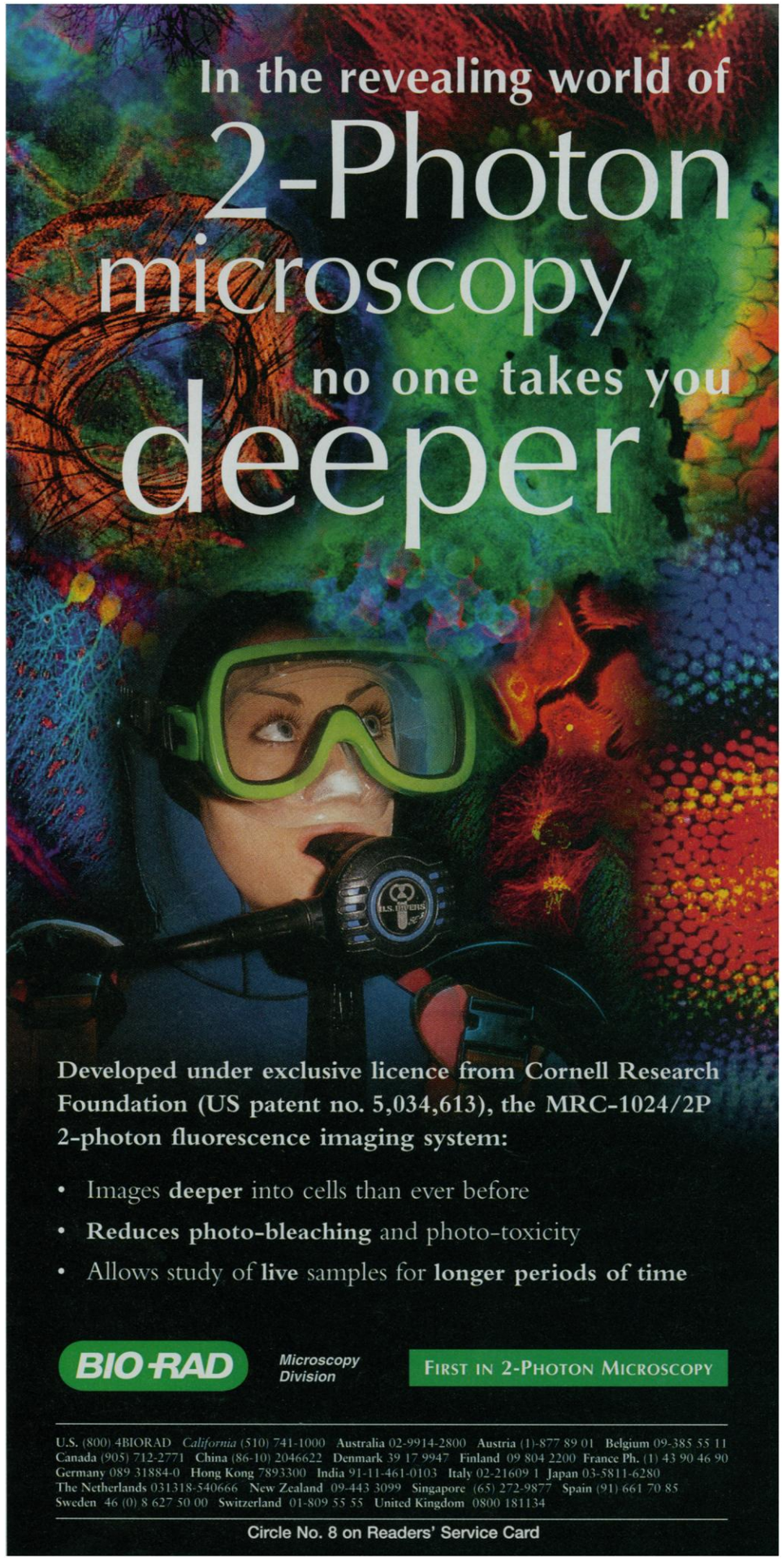
Response: One question raised by these letters concerns what our research actually showed. Pinker says the idea "[t]hat infants learn words by remembering sequences of sounds is not new or controversial." We

agree (*1*). Our own work is, however, the first empirical demonstration that 8-month-old infants can actually perform the sequential statistics that such an idea requires. Our proposal about how the underlying learning mechanism operates is largely equivalent to that described by Clark *et al.* We do not assume, however, that learners need have knowledge about *word* boundaries. Whether this mechanism is particular to language, or is instead applied to many segmentation problems, is yet to be determined; as Pesetsky *et al.* state, our research does not yet distinguish between these possibilities. In either case, this type of rapid and rather complex learning, while it may or may not be tied specifically to learning languages, might well be the kind of remarkable skill that permits language learning in humans to occur.

A second question concerns how a statistical mechanism might apply to the acquisition of syntax. Pinker assumes that an extension from words to grammar would involve using the *same* sequential statistic; he then argues that this statistic is insufficient to capture the nature of grammar. We agree. In contrast, Bates and Elman assume that infants can perform a range of statistical analyses, and they express confidence that, somewhere in the mix, such capabilities will be sufficient. Our own view is more cautious. Like Bates and Elman, we suspect that infants may be capable of performing other kinds of complex statistical analyses; that is an empirical question that requires further study. Such findings alone, however, would not solve the acquisition problem. All of the letters emphasize this same point: Linguistic structure cannot be learned through undirected analyses of input sentences, no matter how complex or numerous these analyses may be. Such analyses must in some fashion be focused or oriented by innate predispositions of the learner; otherwise, there is no way to explain why human infants are the only learners who can acquire human languages or why langauges recurrently develop certain types of structures. As Bates and Elman noted in their Perspective, we think that there are several interestingly different ways of implementing such innate predispositions: Innate biases in statistical learning may be different in important ways from innate knowledge of linguistic principles. But both of these implementations involve types of innateness.

We find the current state of neural network research to be an interesting illustration of this point. Neural network models have contributed interesting debates and fresh ideas to the field, but no current mod-

(*continued on page 1276*)



(*continued from p. 1181*)

el is capable of learning a language, or of learning the way that human infants do. Their limits therefore illustrate the important perspectives provided to our field by Noam Chomsky. Chomsky's point was not that there is no such thing as learning; rather, it was that unconstrained learning mechanisms will not, by themselves, correctly learn just those things that every human baby learns (*2*). Our findings do not contradict this point. Instead, they offer the possibility of a mechanism that could turn out to be suitably powerful, but also biased and constrained, so as to perform a piece of the task.

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References and Notes

1. Z. Harris, *Language* **31**, 190 (1955).
2. When models possess human constraints, performance improves; for an example, see the constraint proposed by E. Newport [*Cognit. Sci.* **14**, 11 (1990)] and implemented by J. Elman [*Cognition* **48**, 71 (1993)].

Editorial "Plants"?

Now that the European green crab has been returned to the Arthropoda (Letters, 25 Apr., p. 513) after its temporary domicile in the Mollusca (Random Samples, 11 Apr., p. 203), can we also rescue Illinois' *Thismia americana* (Letters, 25 Apr., p. 514) from the grass family and return it to the Burmanniaceae, a small family much more closely related to orchids than to grasses? Since this *Thismia* is almost certainly extinct, its final resting place should be in the correct family plot.

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I too was amused to find green crabs classed as mollusks in a recent Random Samples item, but concluded that the error was a deliberate editorial "plant" to see whether anyone other than molecular biologists still reads *Science*.

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Editor's note: It appears that *Science* has many readers outside the realm of molecular biology—at last count, more than 50 letters had been received about the "misplaced" European green crabs. Botanists, however, have not been heard from in such numbers about *T. americana*, which was misidentified by *Science* during editing.

We are grateful to all those who read *Science* so carefully and who communicate their concerns to us, and we apologize to crabs, mollusks, and *Thismia* enthusiasts everywhere.

Letters to the Editor

Letters may be submitted by e-mail (at science_letters@aaas.org), fax (202-789-4669), or regular mail (*Science*, 1200 New York Avenue, NW, Washington, DC 20005, USA). Letters are not routinely acknowledged. Full addresses, signatures, and daytime phone numbers should be included. Letters should be brief (300 words or less) and may be edited for reasons of clarity or space. They may appear in print and/or on the World Wide Web. Letter writers are not consulted before publication.

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