

## Reply to Speijer et al.: Does complexity necessarily arise from selective advantage?

We recently pointed out that the distantly related alveolate and euglenozoan protist lineages share several otherwise rare traits and inferred that these traits arose by convergent evolution (1). We also emphasized that such complex molecular traits may evolve through the accumulation of neutral mutations (constructive neutral evolution) rather than selection. Speijer (2) questions both inferences.

Convergence is inescapably linked to level of organization: traits may be similar at one level but fundamentally different at deeper levels. For example, vertebrate and cephalopod camera eyes arose by independent reorganization of homologous subcomponents (3). Similarly, widespread RNA editing exists in dinoflagellate and kinetoplastid mitochondria, but their different mechanisms reinforce the phylogenetic conclusion that these processes originated convergently. The same can be said for characteristics of plastids and nuclear gene expression we highlighted (1). “Epistatic constraints” are not an alternative to convergence: They may economize the role of convergence for evolutionarily related changes, but the ultimate origin of the traits is still convergent.

Whether characters originated because of selection is a thornier question. The assumption that complex systems must confer some advantage and therefore evolve by positive selection is rarely questioned, even in cases with no obvious advantage (or for which multiple mutually exclusive explanations have been proposed), such as kinetoplastid RNA editing. We suggest instead that such systems arise without positive selection through a process of constructive neutral evolution (4).

Speijer (2) raises three objections: Drift is required, editing is expensive, and reversals are impossible. However, drift must fix neutral changes in any explanation of editing (unless every mutation is selected, a ridiculous extreme). Similarly, there is no evidence that eukaryotic genomes are so sensitive to ATP economics that complexity must be meaningfully deleterious. Moreover, in a neutral origin of editing, complexity increases

incrementally and in a ratchet-like fashion in which new neutral changes render previous ones essential. This directionality favors the system's persistence but does not exclude reversal any more than if the system originated by positive selection.

It also is essential to distinguish how a system originated and what it does today. A complex system may originate without selective advantage and subsequently acquire secondary attributes. Secondary attributes may be beneficial, but they do not explain the system's origin. Speijer's model (5) does not seek to explain the origin of kinetoplastid editing but only its later expansion in some lineages. In invoking selection, this model demands uncertain conditions such as strong competition between kin and few cheaters. However, the ratchet-like expansion predicted by a neutral model (4) requires no special conditions: As long as the correction machinery is in place, expansion simply requires the emergence of new guide RNAs, mutation, and drift.

The easy route taken by most molecular biologists is to explain complexity by positive selection. However, we should not dismiss the purely neutral origin of complex systems like editing without evidence. Indeed, the absence of a working model for the origin of editing through positive selection renders the neutral model even more appealing, because it is liberated from the need to justify such an absurd molecular system with “Just-So” stories.

**Patrick J. Keeling<sup>a,1</sup>, Brian S. Leander<sup>a</sup>, Julius Lukeš<sup>b,c</sup>**

<sup>a</sup>Canadian Institute for Advanced Research, Departments of Botany and Zoology, University of British Columbia, Vancouver, BC, Canada; <sup>b</sup>Biology Centre, Institute of Parasitology, Czech Academy of Sciences, and <sup>c</sup>Faculty of Sciences, University of South Bohemia, České Budějovice, Czech Republic

1. Lukeš J, Leander BS, Keeling PJ (2009) Cascades of convergent evolution: The corresponding evolutionary histories of euglenozoans and dinoflagellates. *Proc Natl Acad Sci USA* 106:9963–9970.
2. Speijer D (2010) Does complexity necessarily arise from selective advantage? *Proc Natl Acad Sci USA*, 10.1073/pnas.0911933107.
3. Ogura A, Ikeo K, Gojobori T (2004) Comparative analysis of gene expression for convergent evolution of camera eye between octopus and human. *Genome Res* 14:1555–1561.
4. Stoltzfus A (1999) On the possibility of constructive neutral evolution. *J Mol Evol* 49:169–181.
5. Speijer D (2006) Is kinetoplastid pan-editing the result of an evolutionary balancing act? *IUBMB Life* 58:91–96.

Author contributions: P.J.K., B.S.L., and J.J.L. wrote the paper.

The authors declare no conflict of interest.

<sup>1</sup>To whom correspondence may be addressed. E-mail: pkeeling@interchange.ubc.ca.

# AUTHOR QUERIES

## AUTHOR PLEASE ANSWER ALL QUERIES

- Q: 1\_Please contact PNAS\_Specialist@dartmouthjournals.com if you have questions about the editorial changes, this list of queries, or the figures in your article. Please include your manuscript number in the subject line of all e-mail correspondence; your manuscript number is 200911933. Please (i) review the author affiliation and footnote symbols carefully, (ii) check the order of the author names, and (iii) check the spelling of all author names and affiliations. Please indicate that the author and affiliation lines are correct by adding the comment "OK" next to the author line. Please note that this is your opportunity to correct errors in your article prior to publication. Corrections requested after online publication will be considered and processed as errata.
- Q: 2\_Please provide postal code for all affiliations and complete affiliation b.
- Q: 3\_Please review the information in the author contribution footnote carefully. Please make sure that the information is correct and that the correct author initials are listed. Note that the order of author initials matches the order of the author line per journal style. You may add contributions to the list in the footnote; however, funding should not be an author's only contribution to the work.
- Q: 4\_Because PNAS does not allow the use of a pronoun without a specific antecedent, the word "traits" has been added to the clause "... and inferred that these traits arose by convergent evolution." If you prefer a noun other than "traits," please supply it.
- 
-