should be compared with Lewontin's values of 0.063:0.083 (6). We leave it to the reader to judge whether the differences represent biologically significant discrepancies. Averaging all of the estimates, after normalization of the values of Smouse *et al.* to percentages, yields 0.076:0.057, or a ratio of 1.3:1 of genetic variation among major races to genetic variation among ethnic groups. We reiterate the conclusion that there is approximately as much genetic variation among ethnic groups within major races as there is among the races.

Devlin *et al.* also say they are against additional research to obtain data relevant to population substructure for DNA-typing genes because they believe that new data will not resolve the population genetics debate. But new data have already been obtained (*11*) that categorically support our original conclusions (*4*), as well as those of the NRC report (*1*), and refute the arguments of Devlin *et al.* The data are from populations of ethnic Finns and Ethnic Italians as well as an ethnically heterogeneous Causasian population whose DNA was typed using several highly polymorphic markers (*11, 12*). The principal findings were as follows. (i) The ethnic groups often have significant differences in allele frequency distributions. (ii) Genetic differences between the ethnic groups could not be detected by conventional tests of Hardy-Weinberg equilibrium or linkage equilibrium—the tests are virtually useless for detecting substructure in human populations. (iii) When probabilities of DNA profiles were estimated using the product rule with frequencies from the "wrong" ethnic database (Italian database for Finns, Finnish database for Italians), 77% of the estimated probabilities were artificially small—34% by a factor of more than 10 and 4% by a factor of more than 100. (iv) When probabilities of DNA profiles were estimated using the product rule with frequencies from the mixed Caucasian database, 80% of the estimates were artificially small. Points (iii) and (iv) contradict the assertions that "even when there is substantial substructure, the multiplication rule still yields adequate approximations" and that "the methods used in court are already conservative." On the contrary, the new data demonstrate that the methods currently used in court are not conservative—they are systematically prejudiced against the defendant—and no amount of argument will make them conservative.

As for the interim ceiling principle recommended by the NRC (*1*), we agree that the lower bound of 10% used for allele frequencies is arbitrary. Everyone agrees that it is conservative, and some believe that it is too conservative. Whether or not it is excessively conservative is a matter that can be resolved empirically by ethnic group studies of the kind abjured by Devlin *et al.* In the Finnish and Italian data, the interim ceiling principle was not excessively conservative for genotype probabilities greater than 5×10^{-6}. Only additional data will reveal the general robustness and degree of conservatism of the interim ceiling principle. The call for "no new data" will only guarantee more contentiousness and controversy.

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References and Notes

1. Committee on DNA Technology in Forensic Inference, *DNA Technology in Forensic Science* (National Academy Press, Washington, DC, 1992).
2. Affidavit introduced as exhibit in *People* v. *Michael Halik*, Sup. Ct. Los Angeles, Cal., cit. VA843, decided 26 September 1991.
3. California Appellate Court, 1992 WL 184530 (Cal. App. Ct. 1 Dist.); Massachusetts Supreme Court, 1992 WL 171780 (Mass.).
4. R. C. Lewontin and D. L. Hartl, *Science* **254**, 1745 (1991).
5. R. Chakraborty and K. K. Kidd, *ibid.*, p. 1735; R. C. Lewontin and D. L. Hartl, *ibid.* **255**, 1054 (1992); R. Chakraborty and K. K. Kidd. *ibid.*, p. 1053.
6. R. C. Lewontin, *Evol. Biol.* **6**, 381 (1972).
7. J. B. Mitton, *Am. Nat.* **112**, 1142 (1978).
8. M. Nei and A. K. Roychoudhury, *Evol. Biol.* **14**, 1 (1982).
9. P. E. Smouse, R. S. Speilman, M. H. Park, *Am. Nat.* **119**, 445 (1978).
10. B. D. H. Latter, *ibid.* **116**, 220 (1980).
11. D. E. Krane, R. W. Allen, S. A. Sawyer, D. A. Petrov, D. L. Hartl, *Proc. Natl. Acad. Sci. U.S.A.* **89**, 10583 (1992).
12. These data have been provided to the Federal Bureau of Investigation and to the Forensic Branch of the British Home Office for independent analysis.

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Extraterrestrial Intelligence

Ernst Mayr (Letters, 12 Mar., p. 1522) argues against the NASA search for extraterrestrial intelligence (SETI) on the basis that "only one of the approximately 50 billion species that have lived on Earth was able to generate civilizations. Among these approximately 20 civilizations, only one developed electronic technology." The implication is that Earth history suggests that the evolution of intelligence and technology is rare, and so it would be fruitless to search. The quoted facts actually tell us something different and trivial: The first species to develop intelligent civilizations will discover that it is the only such species. Should it be surprised? Someone must be first, and being first says

nothing about how many other species had or have the potential to evolve into intelligent civilizations, or may do so in the future. Indeed, that so many species evolved in the terrestrial biota demonstrates its flexibility and its ability to exploit any characteristic, such as intelligence, that would enhance the fitness of a species. We might worry that intelligence is rare only if a few species evolved in biotas.

Similarly, among many civilizations, one will be the first, and temporarily the only one, to develop electronic technology. How else could it be? The evidence does suggest that planetary systems need to exist in sufficiently benign circumstances for a few billion years for a technology-using species to evolve. This guides us in selecting the classes of star in which to search for signs of technological activity. Such guidance is used in the NASA SETI program, which is well justified and merits the some $10 million per year, or 5 cents per person, that is assigned to it. Those who contemplate the possibilities of life, civilizations, and technology in space should never underestimate the opportunistic nature of biological systems or the enormity of cosmic time.

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Mayr is always at his best when speaking ex cathedra, but in his letter of 12 March he makes some pronouncements that are clearly at variance with the facts. At the same time, he seems to argue that no search for extraterrestrial intelligence should be attempted because he has already decided on the outcome. Would that all scientific experiments could be done so cheaply.

A search for extraterrestrial life has indeed been recommended by the last three National Academy of Sciences (NAS) Astronomy and Astrophysics Survey committees; but it has also been recommended by other groups in the NAS and elsewhere that included noted biologists and paleontologists, many of whom disagreed with Mayr about this issue.

In fact, it is the general and not the particular circumstances of Earth's evolutionary history that motivate a search for life elsewhere. What happened here could, in the broadest outlines, have happened elsewhere—conservatively estimated at approximately 60 billion "elsewheres" (planets) in the Milky Way galaxy alone. The question is, "Did it?" By using available technology, we can determine the existence of life elsewhere in the universe now by detecting artificially generated radio signals coming from other solar systems. In the final analysis, I believe it is better to perform such experiments than to be walled off from the real world by the opinions of experts.

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I agree with Mayr that evolution elsewhere in space has a vanishingly small probability of replicating our own history, but I am much more optimistic about the general issue. Evolution on Earth is replete with examples of adaptive convergence which, were they not so well documented, would most probably be deemed impossible. The striking similarity of certain marsupial and placental mammals is the common classroom example, and other cases abound.

Powered flight evolved independently many times and, although the wings of bats, birds, pterosaurs, and insects are structurally very different, their functions are the same. SETI does not depend on finding a perfect replica of human intelligence, but only something functionally close enough to be recognizable in a listening, as opposed to a communicating, mode. And evolutionary biologists do not know enough yet about the phenomenon of convergence to rule out the independent evolution of intelligence. Research on convergence has not gotten beyond description of cases and some pallid plausibility arguments based on unconstrained natural selection.

The prognosis for SETI is further enhanced if one considers the possibility that seemingly intelligent behavior need not be of the conscious, humanoid type (*1*). A surprising variety of living organisms generate relatively strong electrical pulses, and some can detect radio signals; this suggests that intraspecies electronic communication could be the hard-wired product of ordinary Darwinian evolution.

I am optimistic about SETI because it constitutes a bold experiment in exobiology, a field where we have little to go on but where the past few decades have witnessed many surprises—phenomena that were shown a generation ago to be impossible on the basis of "first principles." Even in this time of fiscal austerity, I do not think we should eliminate one of the few federal science projects that has not been promoted as a sure thing. After all, if SETI succeeds, the returns will be incalculably large.

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References

1. D. M. Raup, *Acta Astronaut.* **26**, 257 (1992).