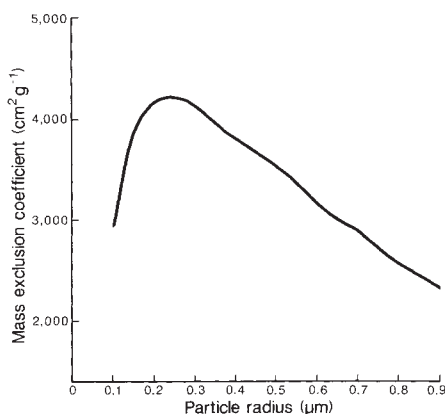


Ice particles and the greenhouse

SIR — Within the framework of a suitable model the properties of the Earth's greenhouse can be calculated from tables of absorptivities of the greenhouse gases¹. We find that, taking the Earth's albedo to be 0.30, the Earth's effective infrared temperature with no greenhouse would be about 255 K. Adding the present-day greenhouse gases raises the Earth's mean temperature to about 292 K, in agreement with experience. Doubling the present atmospheric CO₂ content would raise the mean temperature by a further 1.5 °C without including a knock-on-effect from water vapour. The latter is what one cares to make it. A typical increase of a factor of 2 gives a rise of about 3 °C.

Even slight variations of circumstances that have been kept constant could alter the result of this investigation; the albedo is one such factor. Increasing the Earth's albedo from 0.30 to 0.315 would conceal the doubling of CO₂. The albedo depends on clouds in the troposphere, and on the nature



The backscatter mass exclusion coefficient of spherical ice particles averaged over the solar spectrum and the sunlit hemisphere, as a function of particle radius².

of the Earth's surface — oceans, deserts, grasslands, forests, crops, ice and snow.

Small ice crystals in the mesosphere also significantly affect the albedo. The figure shows the average mass coefficient for the exclusion of solar radiation due to backscattering by spherical ice grains uniformly distributed over a sunlit hemisphere². The computations are based on Mie theory combined with integrations over a hemisphere and an averaging with respect to the solar spectrum. We note that for particles with radii of a few tenths of a micrometre, a typical value of the mass exclusion coefficient is about 4,000 cm² g⁻¹, the result being insensitive to the precise particle size. Taking the mass loading of the particles over the whole Earth to be 10¹² ξ g (where ξ is a parameter that ranges from about 0.1 to 10), the albedo is increased by 10¹² ξ × (4,000)/5 × 10¹⁸ = 8 × 10⁻⁴ ξ (the surface area of the Earth being ~ 5 × 10¹⁸ cm²). A value of ξ of order 10 would therefore yield a cooling of the Earth sufficient to cancel out a doubling of the atmospheric CO₂

content. Although such a value of ξ is not currently operative, the total water vapour content of the high atmosphere would, if condensed, be far more than sufficient. The measured mid-stratospheric water vapour content is indeed in excess of 10¹⁵ g. Conditions for the condensation of water vapour into particles appear to be delicate³, suggesting that no great change would be needed to increase ξ substantially. Episodes of extensive ice-crystal condensation could be triggered by either terrestrial or extra-terrestrial

African fishes

SIR — Meyer *et al.* conclude¹ that morphological diversification in flocks of cichlid fishes in Lake Victoria occurs without much molecular evolution. This agrees with our own data on hybrids between different species of cichlid fish from Lake Victoria, which can be bred easily over several generations²⁻⁴. In addition to the molecular data on mitochondrial DNA, our results show the genetic compatibility for the entire genome of some Lake Victoria 'haplochromines'.

But we disagree with Meyer *et al.*'s second conclusion that Lake Malawi species are more closely related to those of Lake Victoria than to those of Lake Tanganyika. We tested by hybridization the genetic compatibility of *Astatotilapia burtoni*, a riverine species from the Lake Tanganyika basin, with *Astatotilapia nubilus*, a riverine species from the Lake Victoria basin. The fertility of the hybrids between these species suggests that they are genetically almost as compatible as haplochromines from the Lake Victoria basin^{2,3}. Moreover, we also tried to breed hybrids between the monotypic genus *Astatoreochromis alluaudi* and several haplochromines of Lake Victoria. According to Meyer *et al.*, this species should be more closely related to Lake Victoria haplochromines than to those of Lake Tanganyika. We succeeded, however, in breeding only one hybrid population between *Astatoreochromis alluaudi* and *Astatotilapia 'black lividus'* (a so far undescribed species of Lake Victoria). These hybrids reproduced, but the eggs deteriorated before hatching. This is the only evidence for sterile hybrids that we have obtained so far. *Astatoreochromis alluaudi* is also the only species in Lake Victoria that stands out in its protein characteristics⁵.

We believe that Meyer *et al.* should include molecular data from the riverine Lake Tanganyika haplochromine *A. burtoni* in their analysis. Their second conclusion will then be that some haplochromines of different lakes arose from more closely related riverine species; in other words, that segregation had started before the lakes formed. The major problem of the species flocks of the great African lakes is clearly how they have evolved and are maintained in sympatry,

factors connected with the supply of condensation nuclei. Perhaps this is what happened during the Little Ice Age.

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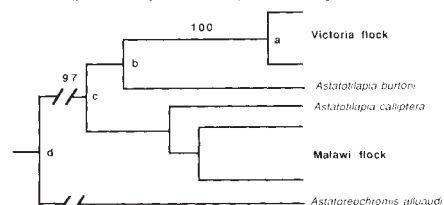
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while obviously relying exclusively on pre-mating barriers — a significant ethological problem in its own right⁴.

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MEYER *ET AL.* REPLY — Inferring relationships from patterns of hybridization is risky. The hybridization studies involving *Astatotilapia burtoni* males and *Astatotilapia nubilus* females produced only lethal hybrids². Females of *A. burtoni* mated rarely with males of *A. nubilus*, but produced viable hybrids². Numerous studies have shown that hybrid incompatibility, although usually correlated



Evolutionary tree based on comparisons of part of the control region of mtDNA. The region sequenced and the methods used are described by Meyer *et al.*¹. Bootstrap values appear above the two internal branches that are statistically significant (a—b and c—d). The distance from any node to the tips of the descendant branches are roughly proportional to the average number of base substitutional differences between species united by that node. The root of the tree (node d) was determined by using *Julidochromis* as an outgroup (see ref. 1). The two sequences of *Astatotilapia* have been deposited in Gen Bank with accession numbers X58151 (A.c.) and X58152 (A.b.).

with phylogenetic distance, is not an accurate metric for building trees and time scales.

In anticipation of questions about *Astatotilapia*'s phylogenetic status, one of us (A. M.) sequenced the most variable part of the control region of mitochondrial DNA from two key species, *A. burtoni* and *A. calliptera* (a non-endemic cichlid from Lake Malawi). Three *Astatotilapia* species from the Lake Victoria basin (*A. nubilus*, *A. elegans* and *A. piceatus*) had already been tested¹. The figure shows a tree relating the two new sequences to those of the species flocks in

Lakes Victoria and Malawi as well as to *Astatoreochromis alluaudi*. The results confirm (with 97 per cent confidence) the hypothesis, suggested by interspecific hybridization studies, that *A. burtoni* is a closer relative of these flocks than is *Astatoreochromis*. This analysis also suggests (although not significant statistically) that *A. burtoni* is closer phylogenetically to the Lake Victoria flock than is the Lake Malawi flock.

Furthermore, and contrary to the hypothesis of Crapon de Caprona and Fritzsche above, the members of the Lake Victoria flock (including *A. nubilis*, *A. elegans* and *A. piceatus* are more closely related to one another mitochondrially than to *A. burtoni*. The bootstrap value that shows the reality of the a-b lineage in the figure is 100 per cent. We infer that the Lake Victoria flock arose long after the splitting of the *A. burtoni* lineage from the a-b lineage. Our molecular estimate of the time of most recent common ancestry for the Lake Victoria flock is 200,000 years¹, which implies that the flock is younger than the lake (250,000 to 750,000 years old⁶). Thus, our results cast doubt on Crapon de Caprona and Fritzsche's model, above, according to which segregation occurred within the flock before the lake formed.

Another notable feature of the figure is

that *Astatotilapia* species are candidates for being the sister groups of both the Lake Victoria and Lake Malawi flocks. Although *Astatotilapia* is not a monophyletic group (mitochondrially), these particular species may be close in body plan and lifestyle to the ancestral state for these two flocks, and this may help to explain their ability to hybridize with distant relatives.

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'Life' not critical?

SIR — Bak *et al.*¹ have presented evidence that the cellular automaton, the 'game of life', develops into a self-organized critical state², characterized by a $D(T) \sim T^{-1.6}$ distribution of times T required for the lattice to return to equilibrium following a random single-site perturbation. This power law implies an infinite expected equilibration time $\langle T \rangle$. But we believe that this behaviour is an artefact resulting from the relatively small lattices (100 by 100) used in ref. 1.

Self-organized criticality describes situations in which a spatially extended dissipative system spontaneously adjusts itself, without deliberate tuning of any external parameter, into a state with no finite correlation length or relaxation time, like an equilibrium statistical-mechanical system at its critical point. In a classic example², the addition of sand grains one at a time to an idealized sandpile increases the slope until a critical slope is reached, after which the arrival of an additional grain is likely to trigger an avalanche of any size, up to the size of the entire system, maintaining the mean slope thereafter at the critical value. A general mechanism of such criticality has been elucidated for models having a conserved quantity, such as the amount of sand. But Bak *et al.* suggest¹ that systems that lack any evident conserved quantity may also be critical.

On a finite $L \times L$ lattice, large avalanches are not possible, and the expected equilibration time $\langle T \rangle$ implied by the $T^{-1.6}$ power law is no longer infinite but should increase with L at least as $L^{0.4}$, because the initial per-

turbation can increase in diameter at most linearly with time. Our studies on lattices up to $1,024 \times 1,024$ with periodic boundary conditions (Fig. 1a) show instead that $\langle T \rangle$ approaches a constant value 200 ± 10 for lattices larger than about 100×100 . This suggests a characteristic extinction length of ~ 50 lattice points for perturbations propagating outward from their point of origin.

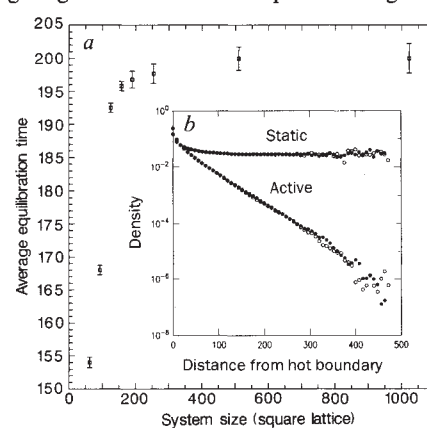


Fig. 1a, Average decay time for point perturbations in the game of life, as a function of linear system size, for square arrays with periodic boundary conditions. Perturbations decaying in ≤ 6 steps are excluded from the average. b, Semi-logarithmic plot of static and active density as a function of distance from the hot boundary, in a 488×256 array with a hot boundary on the left, a free boundary on the right and periodic boundary conditions in the vertical direction. Dots and circles show results of two independent runs of about 30 million steps each.

To determine this extinction length more precisely, we measured active and static densities (see below) in other runs (Fig. 1b) as a function of distance from an inhomogeneous 'hot' boundary, in which the configuration was randomized every 16 steps. The static density approached a characteristic equilibrium value of 0.03 away from the boundary, whereas the active density (here defined as live sites that were not alive 6 steps previously) declined exponentially with a scale length of 42 ± 3 , indicating a uniform rate of extinction per unit distance for perturbations propagating away from the hot boundary.

Our results indicate that the game of life is subcritical, with a large but finite relaxation time of 200 ± 10 steps and an extinction length of 42 ± 3 lattice points, and that the equilibrium state, restored after the decay of perturbations, is a roughly spatially uniform distribution of decoupled local oscillators with a density of ~ 0.03 . The possibility remains, however, that this apparent equilibrium may be metastable with respect to nucleation events too rare to have occurred in any of our simulations so far. This would be the case, for example, if the game of life allowed the existence of configurations analogous to Belousov-Zhabotinsky spiral cores, which cannot be destroyed from outside but instead entrain their surroundings in coherent waves of minimum period⁴.

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