Fig. 3 Averaged velocity of polar wandering as a function of time for different lower mantle viscosities. The upper mantle viscosity (η_2) is fixed at 10^{22} P. The forcing parameter of the Northern Hemisphere is set to 90 m; otherwise, the parameters are the same as in Fig. 2. a, $\eta_1 = 10^{22}$ P; b, $\eta_1 = 2 \times 10^{22}$ P; c, $\eta_1 = 3 \times 10^{22}$ P; d, $\eta_1 = 4 \times 10^{22}$ P.

by a factor of 4, the net polar drift only decreases by about a factor of 2. This behaviour can be explained by the fact that more of the transient flow takes place preferentially in the upper mantle due to a stiffer lower mantle, thus yielding a compensatory contribution to the changes of the inertia tensor.

For this set of plausible mantle viscosity values[26], we find that cyclic forcing of the late Cenozoic ice ages can force a net drift of the rotation pole relative to the surface geography, at a rate of 0 (0.1° Myr^{-1}). This amount is a factor of about 4 times smaller than those derived from the three-layer models[1,2]. We note that the instantaneous rates of polar wander as inferred from astronomical data[27,28] are much higher than the current estimates from palaeomagnetic data[29] with TPW rates of between 0.2 and 0.3° Myr^{-1}. These are, in fact, in close agreement with the steady-state values for the mean drift calculated here.

Our results for a more realistic Earth model reinforces the notion advanced by Sabadini et al.[2] that net polar displacement could be produced by glacial cycles. The main finding to which we wish to draw attention here is that TPW is influenced by the 'slow' physics of the system, brought about by a slowly decaying mode, which is ascribed to mantle phase transitions. Hitherto, this fact has not been considered in climate studies of ice ages. Geological evidence indicates the extent of glaciation from earlier ice ages in the Phanerozoic were of a comparable magnitude with those of the Pleistocene, whose forcing parameters have been used in this study. From the mean polar speed calculated above, this would imply that a significant amount of net polar drift 0 (10°), which would be sufficient to disrupt the geographical conditions conducive for maintaining glacial cycles, will eventually be attained in about 30–50 Myr. This length of time is comparable with the duration of earlier glacial epochs, such as those which occurred in the Permian and Silurian ages[30]. We suggest that the characteristic time scale of major ice age epochs 0 (10^7 yr) may be controlled by the slowest relaxing mode of the mantle, due to the presence of phase transitions.

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Parallel versus serial processing in rapid pattern discrimination

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When stimuli are available for just a brief period (~ 100 ms) only restricted spatial information can be processed by the visual system. If the stimuli are presented very briefly, eye movements are not possible. The time during which the after-image of the stimulus is available for inspection is terminated by presentation of a masking pattern. We show here that in these conditions a small pattern is easily detected against a background made up of many others, only if this target pattern differs from the background patterns in certain local features. In this case the detectability of the target is almost independent of the number of background elements, suggesting that a parallel process is operating. Detection of patterns not differing from their backgrounds in such features requires focal attention which is a serial process. The aperture of this attention is scaled to minimize the number of shifts of attention required.

Many factors determine the ease with which a visual pattern can be discriminated from those surrounding it. Julesz[1] has described a theory of preattentive texture discrimination based on a few conspicuous local features, which he called 'textons'. A similar theory has been proposed by Triesman and Gelade[2]. An example of such preattentive texture discrimination is shown in Fig. 1A, in which (when viewed from up to about seven times picture height) the regions made of Xs and Ls in the upper half perceptually segregate while the regions made of Ls and Ts in the lower half do not. To determine the spatial configuration of these lower regions, element by element, scrutiny is required. We call this concentration on small areas 'focal attention'. Differences in the density of textons within a region give rise to preattentive texture discrimination while small differences in their positions do not. For example, the two non-overlapping perpendicular line segment textons have the same density in the regions made up of Ts and Ls and thus do not yield preattentive discrimination, although inspection by focal attention easily distinguishes between these regions.

We have investigated the relationship between preattentive texture discrimination and rapid pattern discrimination using a paradigm similar to that of Julesz and Burt[3]. In these experiments the stimuli consisted of a hexagonal array of high contrast white figures on a dark background (see Fig. 1B). The diameter of the hexagonal arrays is 15 deg arc; the line segments making

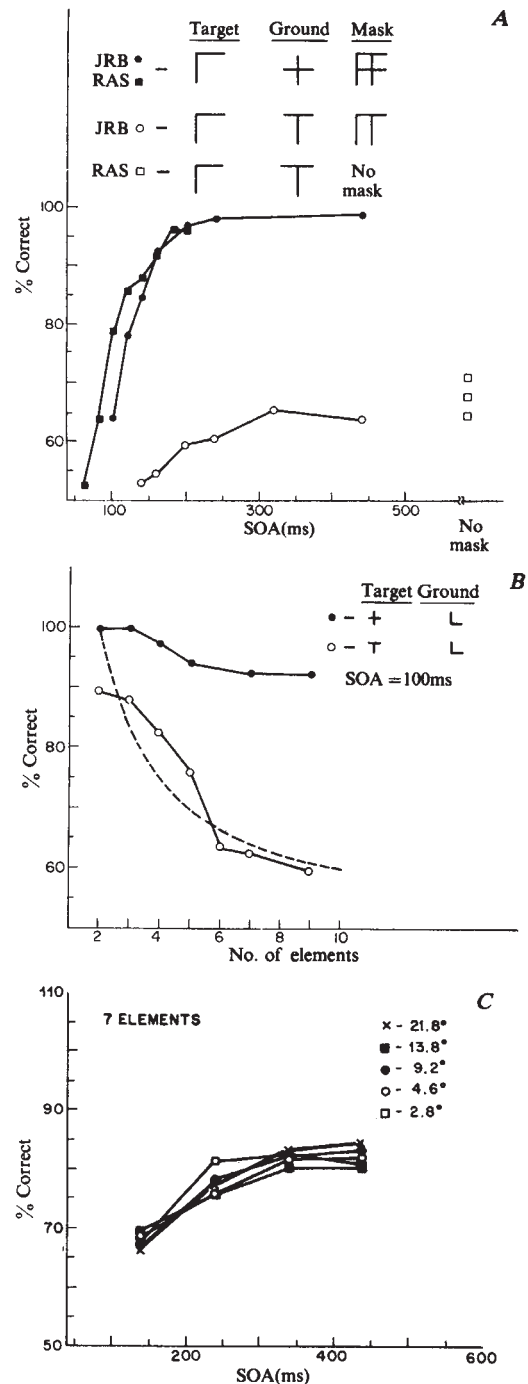* Present address: RCA DAvid Sarnoff Research Center, Princeton, New Jersey 08540, USA.
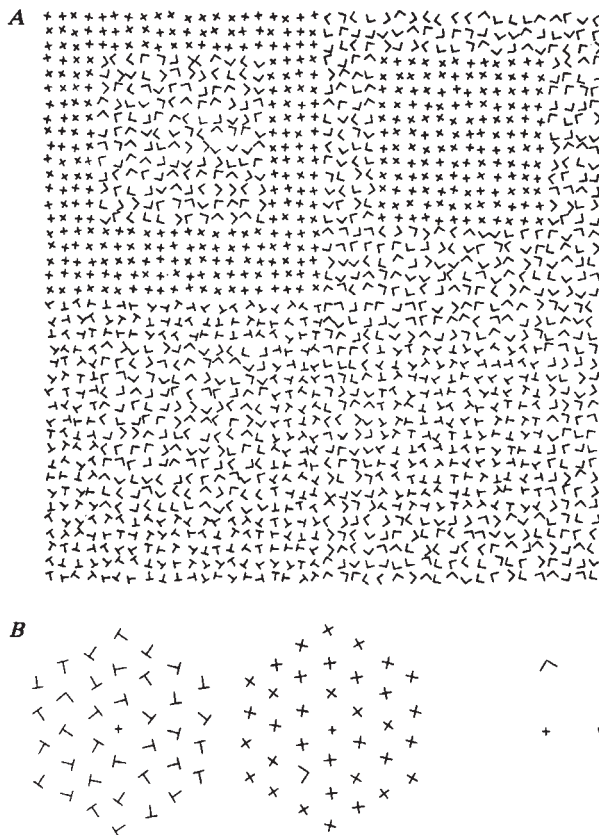
Fig. 1 *A*, Demonstration of preattentive versus attentive texture discrimination. The upper half of the figure contains distinct regions of clearly defined shape. The lower half contains embedded regions of identical size and shape which do not perceptually segregate. *B*, Stimuli of the type used in the experiments of Fig. 2*A* and *B*. Left, lower curve in Fig. 2*A*; middle, upper curve in Fig. 2*A*; right, first point of lower curve in Fig. 2*B*. (Actual stimuli were white figures on a dark CRT face.)

Fig. 2 *A*, Comparison of probability of correct detection of a target element in the presence of 35 background elements. Solid symbols represent the 'L' and 'X', which form strongly segregating textures, while the open symbols represent 'L' and 'T' elements, which do not (see Fig. 1*A*). Data for two experienced observers (J.R.B. and R.A.S.) are shown. The three points at the far right are three independent measurements of performance, without a mask, for R.A.S. *B*, Probability of correct detection of a single target element presented among a variable number of background elements. For description of dashed curve see text. *C*, Demonstration of scaling invariance. Seven elements were presented. Diameter of the stimulus ranged from 2.8 to 21.8 deg. arc.

up the individual elements extend for 50 min arc. The task of the observer was simply to determine whether the elements were all the same, or if one, the 'target', was different. The target was present in half the trials. The position of the target element, if present, was varied randomly from trial to trial within the outer two shells of the hexagonal array. Thus, the observers did not know where it would appear next. The observer fixated the small central cross which was always present. The time available for inspection was limited by applying, after the test stimulus, an erasing flash consisting of elements which were the union of those to be discriminated. This procedure allows study of discrimination using inspection times shorter than the persistence of the after-image.

Figure 2*A* compares discrimination behaviour for the two elements which in Fig. 1*A* yield strong texture segregation, with that for two elements which do not. The test and masking patterns were each presented for 40 ms with a blank interval of variable duration between them. During this interval, the after-image of the test pattern was highly visible but could not, of course, be inspected using eye movements. The use of this brief flash presentation gives many of the benefits of retinal stabilization without sophisticated equipment. The data are plotted as a function of the interval between the test and mask onsets ('stimulus onset asynchrony' or SOA). The results in the two cases are clearly different. In the case of one L among 35 Xs (shown at the centre of Fig. 1*B*) detection is almost perfect by SOA of 160 ms, while for one L among 35 Ts (as in the example on the left of Fig. 1*B*) the asymptote is not reached until about 300 ms SOA and performance never exceeds about 62% correct.

Perceptually, the L among the Xs stands out, even when the inspection interval is very short, while the L among the Ts must

be sought out. This introspective observation is supported by results for detection of the L when only one background T is presented, as shown on the right in Fig. 1*B*. In this case performance is similar to that for one L among 35 Xs. This suggests that the L among Xs somehow marks its own location, as if it were presented alone on a blank field. We believe that the texton difference between the X and L marks the location of the disparate element, removing the need to find it by serial

search. Based on the asymptotic performance level of 62% correct in the L among Ts case, we can estimate (as described below) the number of elements the observer was able to inspect to be about seven. (If we assume that the observer searches at random, but never inspects the same element twice, the probability of seeing a single target element among N total elements is n/N, where n is the number of elements inspected. At 62% correct discrimination, the probability that the target is seen is 25%, thus $n \approx 7$.) As the asymptote is reached by about 350 ms SOA (roughly the persistence time of the after-image[4]) we can then infer that it requires on average 50 ms to scrutinize a single element and move to another.

Further evidence for this parallel versus serial distinction is given by the data of Fig. 2B. Here the total number of elements presented was varied, and as described above, the task was to determine whether one of them was different. The inspection time was fixed at 100 ms to limit the amount of searching by focal attention. Once again, there was a very different pattern of results in the two cases. When the target was an X, the drop in discrimination performance when the number of background Ls was increased was slight. When the target was a T, however, performance fell off rapidly. The dashed curve approximating the latter set of points is based on the assumption that only two of the elements can be scrutinized in the 100-ms inspection interval, and that these elements are chosen randomly. (Based on the assumption that a given element is not inspected more than once, one derives a hypergeometric distribution giving the probability of seeing the target. In accordance with this distribution, the curve shown falls to chance performance as $2/n$, where n is the number of elements. This assumption also implies that the variance of the measured performance should be in accordance with the hypergeometric distribution; however, to test this more data would be required.) The rough correspondence between this curve and the data is consistent with a serial interpretation. The decline in detectability of the target with an increase in the number of background elements is also consistent with a parallel model if we assume that the signal-to-noise ratio falls as the number of background elements grows. In addition, it would have to be assumed that in the X versus L case no such noise increase occurs. Even with these assumptions it is not clear how this model would explain the difference in curve shapes seen in Fig. 2A.

As noted above, the serial search cannot involve eye movements, as the test field is presented for only 40 ms. It is rather the process by which the observer serially shifts a region of focal attention from one element to another, in order to identify it. As demonstrated by Posner[5] among others, attention cannot simultaneously be devoted to multiple loci. The difference between the 'same textons' and 'different textons' cases is that in the latter, this search is immediately guided to the disparate element if it is present.

The discrimination behaviour described is independent of whether the stimulus falls entirely within the fovea or extends into the near periphery. This was tested over a range of a factor of 8 in size using stimuli consisting of seven elements arranged randomly in a ring centred at the fixation mark. These elements were either all Ts, all Ls, 1 L and 6 Ts, or 1 T and 6 Ls, chosen at random with equal probability. As before, the observer was required to report whether all elements were the same or not. The smallest of these stimuli subtended only 2.8° of visual angle, while the largest was nearly 22° in diameter. Figure 2C shows that this uniform contraction or dilation of the stimulus had little effect on performance. Thus, within the limits imposed by spatial resolution, the stimulus can be viewed from a wide range of distances with similar results. One type of scaling invariance has been well known for over a century (according to the 'Aubert-Foerster law') to apply in experiments involving spatial resolution[6] (an observer fixating the same point from different distances will generally report that an eccentrically placed letter which is resolvable from one distance will remain so when the viewing distance is changed). This suggests that except for the change of spatial scale, the fovea and near periphery function

similarly in the extraction of visual information. The invariance reported here further suggests that the fovea is not especially privileged with respect to the allocation of attention. It was demonstrated by Posner et al.[7] that extrafoveal attention produces as much decrease in the detectability of foveal targets as does foveal attention on the detectability of extrafoveal targets. This idea is extended by the findings reported here, in that the domain of attention can be a small portion of the fovea, only a few minutes of arc in diameter.

These results clearly have implications for interpretation of the large body of data on visual search and detection. Many psychologists have proposed higher level cognitive theories of pattern (usually letter) detection and discrimination which might account for the results presented here. We have not discussed these alternative interpretations because we feel that a much simpler model such as the one described here is sufficient. Of course, there may be much discrimination behaviour that requires explanation in terms of high level cognitive constructs. We suggest, however, that due to the highly variable texton content of letters, the interpretation of many experiments in which the stimuli are arrays of letters or words will be complicated.

The present results suggest that two different processes are involved in perception of briefly inspected patterns. One is a parallel process operating over large areas while the other is serial, limited to a restricted region depending on the stimulus size. Discrimination of certain feature differences can be accomplished rapidly by the former process while other differences require more lengthy serial scrutiny. Interestingly, the same feature differences that yield preattentive texture discrimination are also those detectable by the rapid parallel process. While these findings are consistent with the texton theory mentioned at the outset, the inference of two distinct processes at work does not depend on any specific theory of texture perception.

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Transfer of a dominant gene for resistance to eyespot disease from a wild grass to hexaploid wheat

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Eyespot disease, caused by the fungus Pseudocercosporella herpotrichoides, is responsible for considerable lodging and reductions of yield in extensive areas of wheat cultivation in North and South America, Europe, New Zealand, Australia and Africa[1]. The level of resistance of wheat cultivars is too low, even among the less susceptible ones (that is, Cappelle Desprez and Cerco) and no genes for resistance have to date been characterized in any species. Sprague[2] found a high level of resistance to this disease in the wild grass Aegilops ventricosa and several workers have attempted its transfer to cultivated wheat with only partial success[3-5]. We report here a major dominant gene for resistance, which has been transferred from tetraploid Ae. ventricosa (genomes $D^v D^v M^v M^v$) to hexaploid wheat, Triticum aestivum (AABBDD), using tetraploid wheat, Triticum turgidum (AABB), as a 'bridge' species.