1983). These associations might suggest a function of these proteins in inflammation; on the other hand, when granulocytes are dying and releasing 'inhibitory factors', perhaps it is not surprising that the most abundant cytosolic proteins show up among them.

Doubt also remains about the 'function' attributed to a different calcium-binding protein family, the calpactins or lipocortins. Their inhibitory action on phospholipase A_2, and thus on the synthesis of prostaglandins, may be due merely to sequestration of the substrate (F. Russo-Marie, INSERM U129, Paris). So in each of these families, there is an embarrassing number of abundant proteins which interact with calcium and sometimes with other second-messenger systems, and an increasing need to know what these interactions are for. □

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SPIN-GLASS THEORY

Correcting errors with glasses

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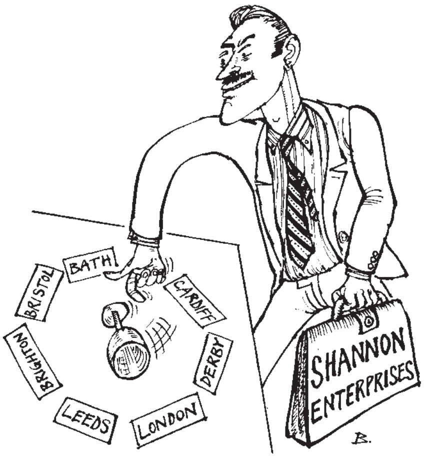
N. Sourlas points out an unexpected relationship between spin glasses and error-correcting codes on page 693 of this issue[1]. Spin glasses can be used as machines to correct automatically errors occurring during transmission in a message if the message is properly encoded before being sent; under special circumstances they can perform this task perfectly. The perhaps counter-intuitive idea that a spin glass, a statistical system, can be used to erase errors rather than enhance them is due to their unusual properties at low temperatures.

The notion of spin glasses was originally introduced by Edwards and Anderson[2] to account for the unusual magnetic properties of certain disordered metallic mixtures. In these materials the coupling constants between the spins on individual ions are random variables, taking positive and negative values with equal likelihood as a function of space. Their relationship to normal glass lies in the fact that both are disordered materials interacting with quenched random couplings.

Such spin-glass models exhibit unusual magnetic behaviour. At high temperatures the spins flip ceaselessly. But as the temperature is reduced each spin becomes fixed in a direction depending on the coupling constants and the positions of the other spins — a phase transition to a spin-glass phase has occurred. There are many such stable positions of the spins for a given set of coupling constants; these are the attractors of the spin dynamics, and depending on the information encoded in the coupling constants these spins can be used to perform various tasks.

For instance, it was recognized by Hopfield[3] that a spin glass could describe an associative memory: encode the memories to be recalled in the coupling strengths of the network and let the spins respond to these couplings. If the initial conditions of the dynamics are close enough to one of the encoded memories, the asymptotic behaviour of the dynamics will fix the spins in positions representing the complete recalled memory — the stored memories are the attractors of the dynamics. Of course too many memories should not be stored, otherwise recall becomes poor.

In fact, a spin glass can be transformed into a general network capable of computing the solution to a large variety of optimization tasks[4] varying from the placement and wiring of components on a chip to the 'travelling salesman' problem, in which the task is to find the minimal tour of N cities, each city being visited



once only. Now spin glasses have found a new use — in information theory.

Information theory, initiated by Shannon[5], relates the information content of a message to its probability of occurrence and examines questions about the transmission of coded information through noisy channels. For example, can a proper choice of code ensure that the errors in a transmitted coded message be made arbitrarily small? Shannon showed that the answer depends on the relative values of the information content of the message and the capacity of the channel. The capacity of the channel is the maximal amount of information transmissible per unit time without error, and increases with the power of the signal while decreasing with the noise.

Shannon's theory does not answer the question of what is the proper way of coding the message to minimize transmission errors. But one possibility is to try error-correcting codes. These achieve their goal by encoding the same message in a variety of ways before transmission. This information would be degenerate if there was no noise in the channel, but with noise the additional information can be used either to check for errors, or even to correct the error if the degenerate information can identify a single error uniquely. What Sourlas shows in this issue[1] is that a class of error-correcting codes can be created where the resulting code after transmission can be identified with the coupling strengths of a spin glass. This spin glass then acts as a machine which corrects some or all of the corruption present; the probability of error still remaining after error correction can be explicitly calculated because the error-corrected message is the attractor of the spin dynamics.

Explicitly, if the message consists solely of a string of bits with values all set to 1 (as Sourlas notes, the error probability is independent of the message transmitted) then the problem of calculating the error probability can be transformed to the task of calculating the magnetization m of this spin glass. This calculation can be performed analytically, and the error probability is simply $(1-m)$. Sourlas analyses a class of models which vary according to the additional degenerate information chosen as the error-correcting terms. One of these models, Derrida's random-energy model[6], can then be shown to have a magnetization $m = 1$ for all signal-to-noise ratios greater than some critical value and consequently this model behaves as an ideal error-correcting code: all transmission errors can be corrected and Shannon's bound on the capacity is saturated.

These results are asymptotic and should not be regarded as solving the problems inherent in the transmission of real messages in noisy channels. For the ideal behaviour to be observed, the messages must be very long and though the coding scheme works for very low signal-to-noise ratios, the number of additional checking bits required becomes enormously large. Nevertheless, this paper does represent one further example of the growing influence of spin-glass theory[7] in branches of science that were previously unrelated. □

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