100 YEARS AGO

A remarkable paper, by Mr. Nikola Tesla, appears in the June number of the *Century Magazine*. The subject is "The Problem of Increasing Human Energy, with Special Reference to the Harnessing of the Sun's Energy"; and though metaphysical and sociological questions receive a large share of attention, the article contains an account of some very interesting electrical experiments… Electrical discharges capable of making atmospheric nitrogen combine with oxygen have recently been produced. Experiments made since 1891 showed that the chemical activity of the electrical discharge was very considerably increased by using currents of extremely high frequency or rate of vibration… The flame grew larger and larger, and its oxidising action more and more intense. From an insignificant brush discharge a few inches long it developed into a marvellous electrical phenomenon, a roaring blaze, devouring the nitrogen of the atmosphere and measuring sixty or seventy feet across. The flame-like discharge visible is produced by the intense electrical oscillations which pass through the coil and violently agitate the electrified molecules of the air. By this means a strong affinity is created between the two normally indifferent constituents of the atmosphere, and they combine readily, even if no further provision is made for intensifying the chemical action of the discharge.

From *Nature* 31 May 1900.

50 YEARS AGO

The subject of population growth or decline has been in the forefront since the Royal Commission on Population began its investigations and deliberations in 1944. Last year its final report was published, and one of its main conclusions was that the slackening of population growth was due to a change in respect of average family size. The Royal Commission outlined the historical background against which the small family came into being: the decline in the importance of the family as a productive unit, the lengthening period during which children remained dependent upon their parents, the advantages of small family size for those struggling for social security and promotion, the increasing and more widely spread knowledge of the techniques of controlled fertility, the changing status of women and the increased opportunities for the enjoyment of leisure outside the home.

From *Nature* 3 June 1950.

other claims that there is no evidence for a thermodynamic glass transition because no such discontinuities are perceivable and the system always crystallizes along the supercooled branch[6], implying that (if it exists) the glass transition can only be a dynamical or kinetic phenomenon. Recent experimental work on colloidal hard spheres[8] supports the second claim.

Adding to the view that glass formation is not a thermodynamic phase transition is the Monte Carlo simulation of Santen and Krauth[2]. They cleverly chose to study two-dimensional systems of hard disks in which each particle has a different size to ensure that the systems do not crystallize. By eliminating any crystallization effects, they can focus exclusively on the nature of the disordered branch. Along this branch, they define the glass transition density to be the point at which the diffusion coefficient (a measure of the mobility of the atoms) becomes vanishingly small — below this density the atoms are mobile (equilibrium liquid), and above this point they are immobile (glass).

An underlying thermodynamic phase transition would be reflected in a discontinuous change in certain thermodynamic properties in crossing this density. In doing these calculations, one must ensure that all of the phase space is sampled without bias (that is, sampling is ergodic). But standard Monte Carlo techniques are known to be non-ergodic when the dynamics slow down near phase transitions. To circumvent this problem, Santen and Krauth use a 'cluster' Monte Carlo algorithm — a method originally introduced to study so-called spin systems near their critical points[9,10]. In particular, by a non-local swapping of large clusters of disks, they avoid the problems that conventional Monte Carlo methods have near critical points and find no evidence for a thermodynamic glass transition. Although the specific case studied here does not settle the issue once and for all (for example, other realistic models for glass formation might behave differently), it is another piece of evidence that adherents of the thermodynamic phase-transition theory will find difficult to discount.

There are several ways in which this work can be taken forward. For example, it could be extended to less idealized systems, such as those in which crystallization is not explicitly suppressed and systems with more realistic interaction potentials (allowing for temperature dependence). The possibility of combining the non-local character of the cluster Monte Carlo method with molecular dynamics simulations in order to study the true dynamics of glasses is tantalizing. ■

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Cognitive neuroscience

Learning how the brain learns

Eilon Vaadia

Methods for monitoring brain activity in behaving animals and humans are being developed with increasing pace. But we are still far from understanding the processes in the brain that give rise to even simple types of behaviour. On page 567 of this issue[1], Laubach and colleagues address the problem by recording the activity of many nerve cells as rats learn a simple task, and combine this approach with sophisticated analytical algorithms.

It is widely accepted that large areas of cortex are involved in any behavioural process, and that these areas contain many modules, each consisting of groups of cells that process specific information. It is often assumed that, once the brain matures, each module and each cell fulfils one specific function. But accumulating evidence indicates that this may not be so. Instead it is likely that each cell participates in several different processes. The brain is also constantly changing, and each cell's effects may be rapidly modified[2]. So it is essential to study a large number of neurons simultaneously to understand how cells communicate and how neuronal interactions are modified in relation to learning and behaviour.

These ideas have been evolving for many years[3–5], but concrete facts have been hard to come by. For a start, it is difficult to record the activity of a large number of neurons while still identifying and isolating each cell. Other problems stem from the limited capacity of computer hardware and a lack of suitable data-analysis algorithms. The study by Laubach *et al.*[1] reflects the intense work being done worldwide to tackle these issues.

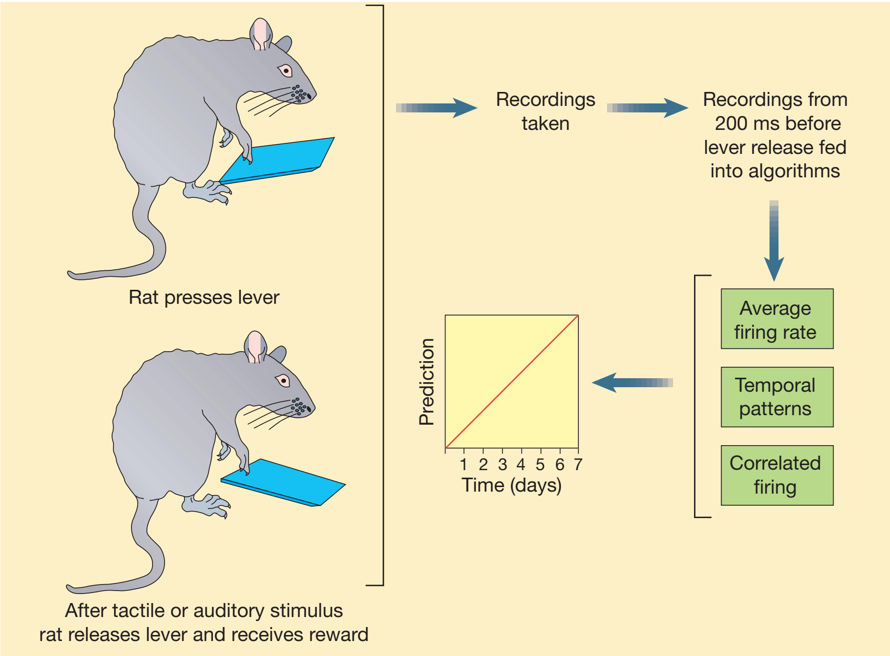

Figure 1 **Brain and behaviour. Laubach *et al.*[1] have attempted to understand how the rat brain functions during a simple learning task (left). The information (shown in green) extracted by the artificial neural networks allowed Laubach *et al.* to predict, with increasing certainty over time, whether or not the rats would perform their simple task correctly — see graph (which does not show actual data).**

components' procedure. They then apply 'independent-component analysis', a method usually used to separate different sources of information from a mixed signal (for example, to extract speech from background noise). They use this technique, and other algorithms, to estimate how much each cell contributes to each independent component, and to what extent the accurate correlated activation of different cells contributes to the available information about animal behaviour.

The results show that information may be encoded in groups of cells, by both rate and temporal codes, as suggested previously[11,12]. Laubach *et al.* make significant progress in deciphering these codes on a trial-by-trial basis. This is important, particularly given the idea that neuronal interactions may change rapidly. The authors also show that both firing rates and temporal patterns change during learning. This suggests that neuronal groups are not rigid entities. On a short timescale, groups of neurons are rapidly activated at the same time as the animal prepares its motor response (see Fig. 3 of the paper on page 569). Cells can contribute to different 'independent components' by firing in concert at different times. On a longer timescale, new groups organize and tune themselves to represent an arbitrary 'mapping' (selected by the researcher) between a sensory cue and a movement. This mapping seems to be highly distributed: in every animal, a small group of 20–30 neurons, spread over quite a large volume of cortex, can be used to predict the behavioural outcome of single trials.

This work provides hope that such approaches will lead to new insights into the mechanisms by which the brain controls behaviour. But there are still issues to resolve. For example, our ability to monitor the same cells for a long period will be improved in the future. Relating the observed modification of neuronal activity to learning per se is difficult, despite the controls used. Interpreting the results of the independent-component analysis is also problematic. Laubach *et al.* used a series of transformations that will leave some readers, including experts, with non-intuitive ideas about the neuronal activity. And, although the methods reveal relevant information about behaviour, it is not possible to test whether the independent components represent independent physiological sources of information.

We are making only the first, tentative steps in a long 'journey to the brain'. Our progress so far might be compared to that of the Wright brothers, who flew the first aeroplane — if their goal were to reach the moon. Time will tell whether or not research such as that by Laubach and colleagues takes us along the right track. But we should continue to pursue even more ambitious attempts to understand how neuronal networks embody

The authors test the hypothesis that information is represented by different groups of neurons, which change their activities and their interactions on both short and longer timescales. Learning-dependent changes in synaptic efficacy that develop on a short timescale (from a fraction of a second to many minutes)[6] have been studied intensively. Mitz *et al.*[7] elegantly demonstrated learning-dependent modification of single-cell activity, as a higher animal (a monkey) learnt to associate an arbitrary stimulus with an appropriate movement. Laubach *et al.*, by contrast, follow both the firing rates of single neurons and the interactions within a group of cells during a simple, but longer, learning process.

The trick was to implant microwires in the cortex, rather than inserting microelectrodes into one site in each 1–3-hour recording session and removing them afterwards. Laubach *et al.* could then follow the development of activity in groups of cells for several days, as a naive rat learnt to press a lever and wait until it was instructed to release the lever. This seems an important achievement — if we can understand the information carried by the neuronal activity.

What is the meaning of 'understanding' in this context? The approach taken by Laubach and colleagues, as in several previous studies[8,9], was to test whether it is possible for us to predict elements of the rats' behaviour by extracting information from the spike activity — that is, the patterns of electrical output — of the sampled cells. Their data analysis aimed to answer one question: how well can we predict the outcome of a single trial (whether or not the rat released the lever at the correct time) from a certain feature of neuronal activity? The authors analysed three features of the spike activity occurring during a period of 200 milliseconds before the start of lever release. These features were the firing rates of all neurons, averaged across the 200-millisecond period; the precise times at which single neurons fired (the temporal firing pattern); and the correlated neuronal activity (Fig. 1).

Analysing the first two of these features is quite simple. The results show — as predicted by intuition and previous studies (for example, ref. 10) — that averaging the firing rate across the 200-millisecond period decreases the amount of available information in the spike trains, as compared with the information carried by the temporal patterns over brief, 10-millisecond intervals. This is not too surprising: many cognitive processes can be accomplished within a short period lasting a few tens of milliseconds.

Studying correlated activity is much more complex, for there are many problems when attempting to extract information from groups of cells — about 20–30 cells in this study. The analysis by Laubach *et al.* is based on complicated procedures, which represent an attempt to interpret data that are complex because of their high dimensionality. To reduce the data representation to manageable levels, the authors first represent the spike trains by the 'principal a computation that can bring about meaningful behaviour. ■

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Quantum decay

A watched pot boils quicker

Peter W. Milonni

Repeated observations of an unstable quantum state — such as a radioactive atom — can make it live forever, or at least much longer than its natural lifetime. This 'watched pot' or 'quantum Zeno effect' has been studied intensively over the past decade. Writing on page 546 of this issue, however, Kofman and Kurizki[1] suggest that a 'quantum anti-Zeno effect' — the shortening of a lifetime due to repeated observations — may be more common.

An unstable state evolves in time into a linear superposition of states. For instance, an excited state of an atom in a vacuum evolves into a superposition of itself and the (stable) states in which the atom is unexcited and has released a photon into the surrounding space. A measurement to determine whether the initial state survives can be formally described as a projection of the superposition back onto the initial state. The quantum Zeno effect can occur when measurements are repeated so rapidly that the time between them is much shorter than the natural lifetime, or 'coherence time', of the state. Coherence times are typically so short that this condition is not satisfied.

Ten years ago[2] an experiment to test the predicted Zeno effect used a radio-frequency field to excite atoms from a state 1 to a state 2, plus a sequence of laser pulses inducing transitions from state 1 to a higher excited state 3. The detection of a spontaneously emitted photon by the 3 → 1 (fast) transition amounts to a measurement of the survival probability of state 1, because spontaneous emission from state 3 can occur only after the atom has already been in state 1, where it can absorb a laser photon. It was found that radio-frequency transitions from state 1 to 2 were diminished by frequent measurements of the survival of state 1. Whether this confirms the quantum Zeno effect is arguable, or perhaps semantic, in that the enhanced survival of state 1 can be understood as an interference effect — rather than projecting the atom into state 1, the laser pulses ('measurements') produce superpositions of states[3,4].

Another example where the survival of a quantum state is affected by sequential measurements occurs in the propagation of a photon through N polarization rotators, each of which rotates the initial ('horizontal') polarization by the angle $\pi/2N$. Left to themselves, the rotators in series rotate the polarization by $N(\pi/2N) = \pi/2$, that is, from horizontal to vertical. Suppose now that a horizontal polarizer is placed after each rotator. The probability of the photon being transmitted by each of these polarizers is $p = \cos^2(\pi/2N)$, and the probability of transmission through all of them is $P = p^N \approx 1 - \pi^2/4N$. The probability of absorption is $1 - P \approx \pi^2/4N$. Many (large N) sequential polarization measurements therefore result in a high survival probability of the initial state. Again it is arguable whether this effect embodies the quantum Zeno effect as originally proposed, but it has been used to demonstrate 'quantum-interrogation' measurements[5,6].

The original prediction[7] of a quantum Zeno effect referred to a spontaneous decay of an unstable particle or state. It is this general situation, where decay is a consequence of a 'reservoir' of possible states to which transitions can occur, that has been revisited by Kofman and Kurizki[1]. They focus attention on the dependence of the decay rate on the energy spectrum of the reservoir states and on the energy spread of the unstable state.

It is clear that the decay rate must depend on the spectrum of reservoir states, simply because the decay is due to transitions to these states. Measurements interrupt and randomize the oscillations of the system and, according to the energy–time uncertainty relation, cause an energy spread $\sim h\nu$, where h is Planck's constant and ν is the frequency of the sequential measurements. This energy spread determines the range of accessible reservoir states and must also affect the decay rate.

The main conclusions of Kofman and Kurizki follow from an analysis of the dependence of the decay rate on the energy spread and the reservoir spectrum. The quantum Zeno effect should occur when the energy spread due to repeated observations is large compared with both the width of the reservoir spectrum and the separation in

Geomorphology

Case of the bends

NATHAN BENN/CORBIS

Paul Hudson and Richard Kesel have returned to the Mississippi River of Mark Twain to investigate the rates of movement (migration) of river meanders. The inspiration for their study was not literary, however, but old surveys of the 1,700-km lower stretch of the river from Cairo, Illinois, to the Gulf of Mexico. The surveys concerned were carried out between 1877 and 1924 — a time when the river was still largely unconstrained by human influence. The photograph here is a recent one of the river in the delta region.

Data from smaller river systems and from modelling point to a specific relationship between meander migration rate and the ratio between meander-bend radius and channel width. But as they describe in *Geology* (**28**, 531–534; 2000), Hudson and Kesel find that the lower Mississippi does not follow this relationship. The reason, they suggest, lies in the heterogeneity of the deposits through which the river flows. In particular, clay plugs limited the rate of meander migration — the incidence of these plugs is higher in the northern part of their study area (average meander migration 45.2 m yr^{-1}) than in the delta (59.1 m yr^{-1}). **Tim Lincoln**