compatibility conflicts. These viruses are preliminarily designated as rheumoviruses.

G. J. SVET-MOLDAVSKY
D. M. MKHEIDZE
A. L. LIOZNER

Institute of Experimental and
Clinical Oncology,
Moscow.

A. PH. BYKOVSKY

Gamaleya's Memorial Institute,
Moscow.

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GENERAL

Holographic Model of Temporal Recall

How do we manage to recognize immediately, and to recall without effort, familiar words, sentences and other behavioural sequences? I suggest that we employ a system which is the temporal analogue of optical holography¹⁻³. The analogy between holography and visual memory has already attracted attention in the literature, but this is not quite the thought that I shall pursue here; rather I shall consider the time dimension, because any perceptual event must certainly be associated with cerebral happenings which are extended not only in space but in time. If a system of this kind were indeed used by the brain, not only would some familiar phenomena of perception be naturally explained, but the cells or cell clusters responsible for laying down sensory information should have a certain property which might be accessible to experimental test.

The system which I have in mind is most easily described with the aid of a concrete example. Imagine a bank of resonators, rather like the strings of a piano. Their resonant frequencies ν_k are supposed to be evenly distributed over a certain frequency band, with a spacing equal to μ , and the bandwidth of each resonator will be assumed equal to the same constant μ . Each resonator is supposed to be coupled to the input signal $f(t)$ according to the equation

$$\ddot{x}_k + (4\pi\mu)\dot{x}_k + 4\pi^2(\mu^2 + \nu_k^2)x_k = A_k f(t)$$

where x_k denotes the displacement of the k th resonator, and A_k is a coupling constant. Then it can be shown that the total response of the bank, conveniently defined as

$$g(t) = \sum_k (\dot{x}_k + 2\pi\mu x_k)$$

will be proportional to $f(t)$ provided (a) that the coupling coefficients A_k are all equal, (b) that $f(t)$ contains no frequencies lying outside the range of the bank and (c) that μ is sufficiently small—that the resonators are sufficiently densely distributed over the frequency range.

I now imagine that after the passage of a signal $f(t)$, the coupling constant of each resonator is capable of being altered by an amount proportional to the work recently done on it by the signal, that is,

$$\Delta A_k = \lambda \int_{-\infty}^0 f(t) \dot{x}_k(t) e^{4\pi\mu t} dt$$

where the quantity λ is supposed to be the same for each resonator. If the signal consisted of a pulse $f_1(t)$ followed

immediately by another signal $f_2(t)$, then it can be shown that if the coupling constants are subsequently adjusted as shown, a later input of the same pulse will immediately evoke a response $g_2(t)$ proportional to $f_2(t)$. This phenomenon is the mathematical analogue of the following holographic observation: a collimated laser beam is split into two parts; one is directly incident on a photographic plate, and the other falls on an object, the light from which is also incident on the plate. The plate is developed and replaced by its positive print, the hologram; the object is removed, and the hologram is illuminated with the first part of the same laser beam. An observer looking through the hologram then beholds the absent object in its original position. The mathematical analogy is not, however, quite complete, whereas the hologram records the square of the Fourier transform of the wavefront leaving the object, the bank of resonators records the square of the Laplace transform of $f(t)$, because to record the Fourier transform would require a violation of causality.

This result can be generalized in two stages. First, it can be shown that if a signal $f(t)$ is arbitrarily partitioned into an earlier part f_1 and a later part f_2 , then after the bank has "memorized" the whole signal, the input of f_1 will evoke a more or less distinct "echo" of g_2 , immediately afterwards. The distinctness of the echo will be greater the more closely the temporal autocorrelation function of $f_1(t)$ approximates to a delta function at the origin.

Second, the bank may be used for memorizing, at widely different times, a number of different signals $f^{(n)}$, $n=1, 2, 3, \dots$. If these signals are so different that their mutual correlations can be neglected, then the later input of $f_1^{(m)}$ will evoke a more or less distinct echo of $g_2^{(m)}$ uncontaminated by any of the other signals that have also been recorded in the bank.

If the bank is used, in this way, for recording a number of different signals, there will obviously be a limit to the length of any one signal that can be recorded. This limit is, in fact, the reciprocal of the frequency spacing μ . But the bank can be made to regenerate signals of much greater length by connecting it to a regenerative feedback mechanism such that when the response g_n appears the signal f_n is fed back into the bank. Then, if the signals (f_1 then f_2), (f_2 then f_3), and so on, have all been recorded, the input of f_2 will cause the bank to re-create the long sequence (g_2 then g_3 then g_4 then g_5 and so on).

The resemblance of such behaviour to that of memory is sufficiently striking for one to wonder whether the brain may not employ systems of this general kind for recording temporal sequences such as those which are involved in speech and kinaesthetically controlled movement. If so, perhaps groups of cells could be detected which have the property of becoming more responsive to particular frequencies the more they are stimulated at those frequencies. Cells are already known which display an accurately sinusoidal metabolism, and have been tentatively identified as "biological clocks"⁴. Could such cells be vitally involved in the processes of temporal recall?

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H. C. LONGUET-HIGGINS

Department of Machine Intelligence
and Perception,
University of Edinburgh.

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