The use of a digital computer in the study of neuronal properties in the visual system

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The properties of neurones in the visual system are being subjected to ever-closer scrutiny. The most common method for studying these neurones is to compare their responses to different visual stimuli, averaged over 20–200 presentations of each stimulus. As experiments become more sophisticated, the accuracy of these response measurements becomes increasingly important, while the number of stimuli to be compared increases. Since the responsiveness of neurones may change spontaneously during an experiment, comparisons among their responses to different stimuli are rather perilous if all the repetitions of each stimulus are presented in a single block. If the neurone's responsiveness *does* change during the course of an experiment, a false estimate may be obtained of the relative effectiveness of different stimuli.

The results of an experiment can be more satisfactorily interpreted if it is performed so that any changes in responsiveness affect the responses to all stimuli to an approximately equal degree. Rather than present each stimulus for a large number of repetitions in a single block, it is better to present those repetitions as several shorter blocks, distributed over the whole experimental period.

We have used this kind of experimental paradigm in our study of neurones in the cat's visual cortex. The stimuli are presented and the response histograms are accumulated by a PDP-11/20 digital computer. The experimenter may specify the characteristics of up to forty different visual stimuli; they are each presented in a short block for a few repetitions; the blocks are presented in random order. Response histograms are accumulated by the computer, and each histogram is stored in the computer's memory. When all blocks have been presented once, their order is re-randomized and they are presented again; the new histograms are added appropriately to those in memory. We normally repeat this procedure at least five times for each experiment.

Experimental control of this kind all but demands a computer, and its use confers other advantages. For example, mathematical analyses may easily be carried out on the response histograms. While measurement of response amplitudes from X/Y plotter records or photographs is tedious and inaccurate, determination of peak response amplitude, modulation depth in the response, total response in any specified interval or harmonic analysis are simple for the computer. Variability in the histograms may be

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attenuated by convolution with a smoothing function, and data may be stored on magnetic or paper tape for later analysis, saving valuable time during the experiment.

Moreover, the computer can also generate the stimuli – in our case on the face of a cathode ray tube, using a television technique. A trigger signal at the start of each frame of the display interrupts the computer, which then reads through a stored list of numbers at approximately 50 kHz. These numbers are transferred to a digital-to-analogue converter, whose output controls the luminance of the display. Since 90 % of the computer's time is devoted to stimulus generation, the accuracy of timing neuronal responses is limited to the duration of one frame of the display (8 msec, in our case). However, there are great advantages in this mode of operation. Stimuli can be generated which would otherwise require elaborate hardware devices, and calibration problems are virtually eliminated by using a single function generator – the computer – to produce the variety of stimulus wave forms otherwise obtained from many different sources. Finally, since the cost of a computer installation is decreasing, it is rapidly becoming the cheapest way to generate visual stimuli and analyse neuronal responses.