Signal Averaging

The vast majority of modern experiments involve detecting weak signals, usually obscured by random noise. The experiments with easily-detected results were performed long ago.

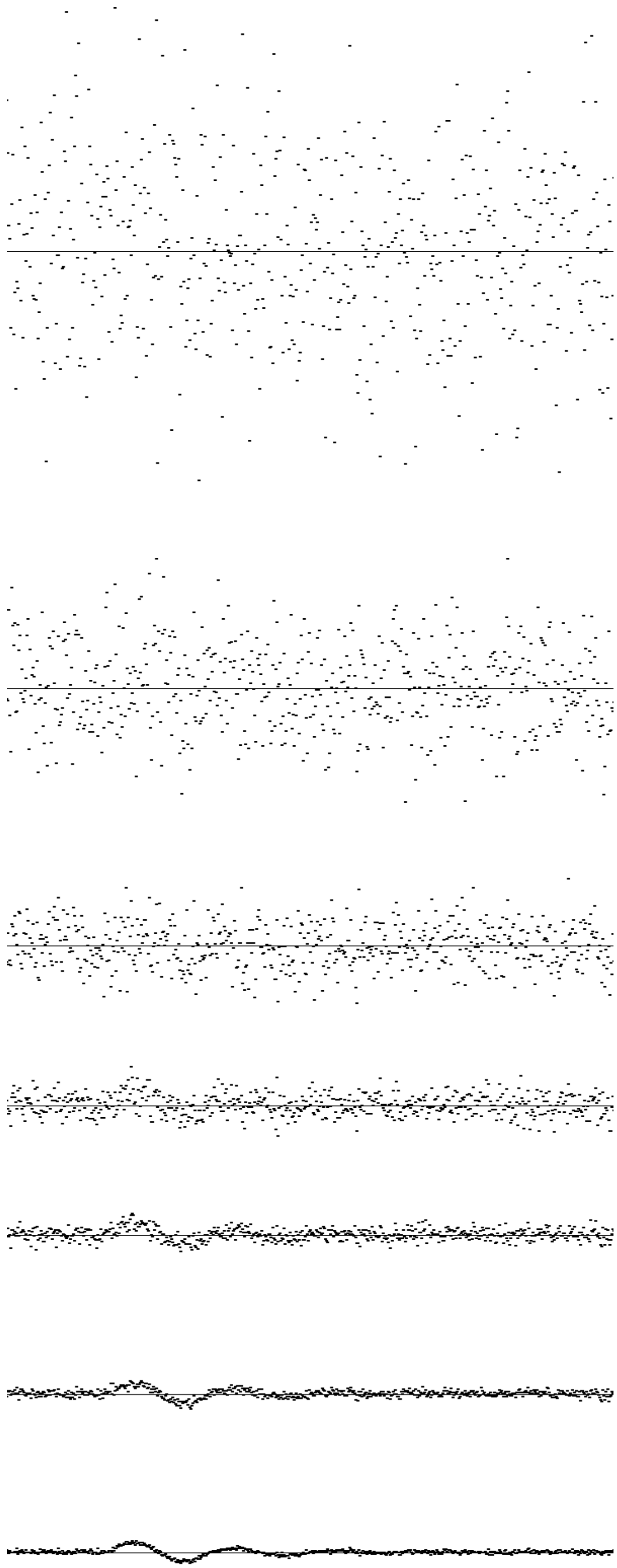
Consider the fascinating experiments performed by Benjamin Libet in the 1970's comparing brain wave signals with a voluntary activity such as occasionally flexing a finger. Electrodes were attached to the subject's scalp to look for brain activity connected with both the flexing of a finger and the time the subject decided to perform the flexing. The subject would look at a rotating visual indication to fix the moment of decision. The finger would then activate a push-button switch.

The brain generates a wide cacophony of signals from which Libet was attempting to find something associated with the finger flexing action. By having the subject repeat the action a great many times, and using the signal averaging technique described below, he made the amazing discovery that the subconscious has already decided to move the finger about 0.3 seconds before the subject is aware of the decision. The subject then has about 0.2 seconds to veto the action or let it happen. Put differently, when we think we have decided to do something, our subconscious has already made the decision 0.3 seconds earlier!

Signal averaging is based on the statistical fact that the sum of n random values (noise) distributed with a normal distribution around zero grows as $\sqrt{n}$ whereas the sum of a constant positive signal value grows linearly with n. Thus, the ratio of signal to noise (s/n ratio) varies as $n/\sqrt{n}=\sqrt{n}$. After averaging 4096 samples, the s/n ratio improves by a factor of 64 over that for just one sample.

This is illustrated in the animation shown in the lab and in the selected images on the next page. To better illustrate how the averaging works, the vertical axis is scaled so as to keep the signal size constant. This scaling makes the noise appear to be getting smaller but does not affect the signal-to-noise ratio. In actuality, both the signal and noise grow, but without the scaling they are both unreasonably small at the start.

In this case, a signal of unknown shape was searched for in relation to a known event. In other experiments a sinusoidal signal of known frequency and phase but unknown amplitude needs to be extracted from noise. In still other experiments, such as the search for extraterrestrial intelligence, a sinusoidal signal of unknown amplitude, phase, and frequency is to be extracted from noise. In each case, the challenge is to extract the greatest information from the available data using a statistical process.



A Single Pass

Average of
4 Passes

Average of
16 Passes

Average of
64 Passes

Average of
256 Passes

Average of
1024 Passes

Average of
4096 Passes