Statistical Efficiency of Natural and Artificial Vision

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INTRODUCTION

In the 1940's Albert Rose drew attention to the high quantum efficiency (5%) of the eye compared with the 1% quantum efficiencies of physical light detectors such as photographic film and video. The subject has attracted considerable interest ever since. Rose defined the quantum efficiency of the eye operationally as the fraction of the incoming quanta (from a dim noise-free display) that would be required to produce the same signal-to-noise ratio as required by the observer to perform a similar task on a bright random-dot display, where each dot was bright enough to be reliably transduced. Around 1960, Barlow and Jones defined the quantum efficiency of vision as the smallest fraction of the light entering the observer's eye that was sufficient to account for the observer's measured level of performance. By using this definition, it was found that quantum efficiency, far from being constant (as one would expect if it represented the fraction of quanta absorbed in the retina), was instead highly variable, depending strongly on nearly every parameter of the stimulus, including size, duration, and background luminance.

Over the past 10 years there has been a resurgence of interest in visual efficiency and noisy displays, and experimenters have begun to find explanations for these early results. Two new efficiencies were introduced around 1980. Barlow defined central efficiency as the smallest fraction of the dots in a bright random-dot display that would be sufficient to account for the observer's measured level of performance. By adding variable amounts of noise to test targets and finding the minimum amount of external noise that disturbs vision, one can estimate the amount of internal noise, or the observer's equivalent input noise. Pelli defined transduction efficiency (which is closely related to Rose's quantum efficiency of the eye) as the fraction of the incoming quanta that is required to account for the equivalent input noise of the observer. Barlow's quantum efficiency of vision is equal to the product of central efficiency and transduction efficiency. Central efficiency has been found to be as high as 83%, but it depends strongly on the parameters of the stimulus, whereas transduction efficiency seems to be around 10% and is relatively independent of most stimulus parameters.

Recently, interest in visual efficiency has expanded from the narrow focus on detection of simple patterns to the general issue of transmission and processing of visual information. Many of these new applications are still not fully solved, since it is not yet clear how to define or measure statistical efficiency for these complex tasks. However, it is clear that notions of entropy and signal-to-noise ratio are helpful in thinking about these problems.

Historically, physiologists have shown little interest in noise. The first step in data collection has generally been to average away the noise in order to look at the signal. There have been occasional papers on the noise of physiological visual signals since the 1950's, usually to measure quantum efficiency. Now, however, there is a new interest in physiological noise, partly to study the dynamics of the system and partly to relate results more closely to psychophysics.

The Rank Prize funds enabled us to organize a minisymposium on The Statistical Efficiency of Natural and Artificial Vision which was held in Cambridge, England, December 15–18, 1986. Many of the papers included here were first presented at that symposium. A second part of this special issue will appear early in 1988.

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