Seminar Visuelle Neurowissenschaften

Pattern Sensitivity
23.04.2007

Wandell, B. (1995). *Foundations of Vision*, chapter 7: Pattern Sensitivity; Sunderland: Sinauer. (p. 195-246)

Overview

1. Computational Theories of the Visual System
2. Fourier Analysis & Spatial Frequency
3. Contrast-Sensitivity Functions
4. Simple & Complex Cells
5. Adaptation, Masking & Facilitation
6. Single Channel & Multiresolution Models

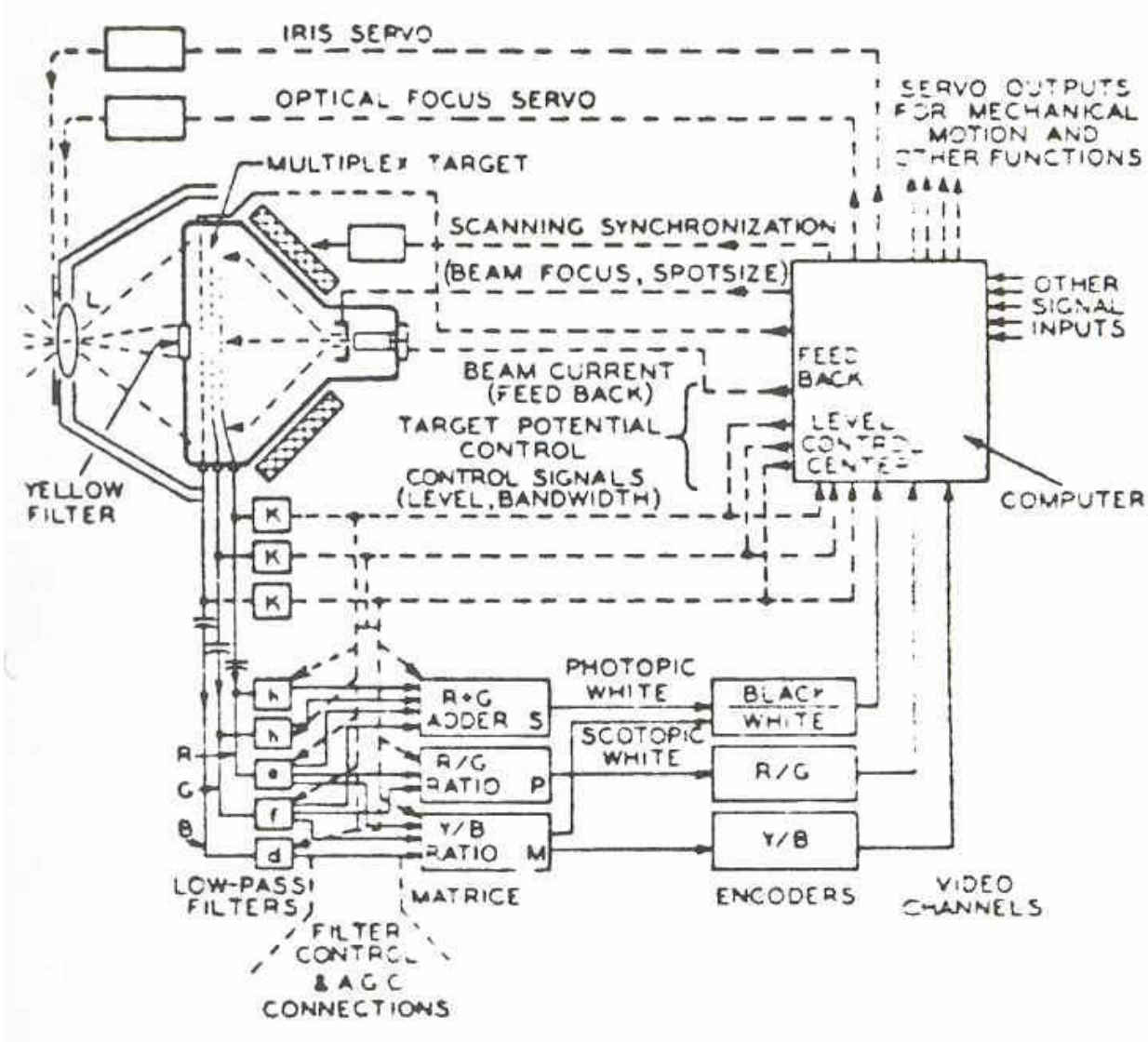
A Computational Model of the Human Visual System

Schade, 1956:

- Computational model: photoelectric analog of the visual system that predicts visual sensitivity
- first measurement of contrast-sensitivity function of the human visual system

A Computational Model of the Human Visual System

Schade, 1956: photoelectric analog of the visual system that predicts visual sensitivity



A Computational Model of the Human Visual System

Schade, 1956: photoelectric analog of the visual system that predicts visual sensitivity

Non-linear theory of pattern sensitivity:

1. the neural image is a shift-invariant linear encoding of the input
2. there is zero phase shift of the linear encoding
3. the vector-length rule: $d^2 = \Sigma n_i^2$ determines visibility

$$\begin{pmatrix} n_0 \\ n_1 \\ \vdots \\ n_{N-1} \\ n_N \end{pmatrix} = \begin{pmatrix} l_0 & \cdots & l_{-N/2} & \cdots & l_{-N} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ l_{N-2} & \cdots & l_0 & \cdots & l_{-N/2} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ l_N & \cdots & l_{N/2} & \cdots & l_0 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ \vdots \\ a_{N-1} \\ a_N \end{pmatrix}$$

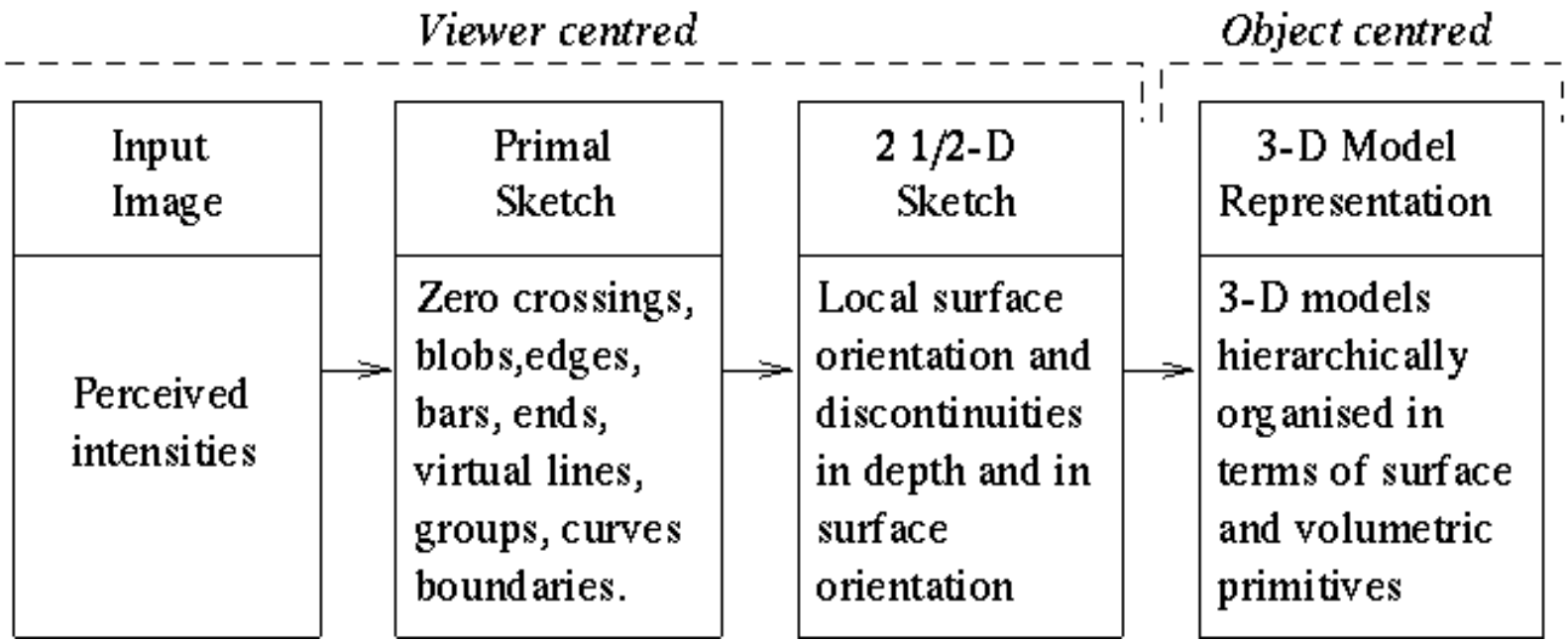
convolution kernel

vector representing neural image

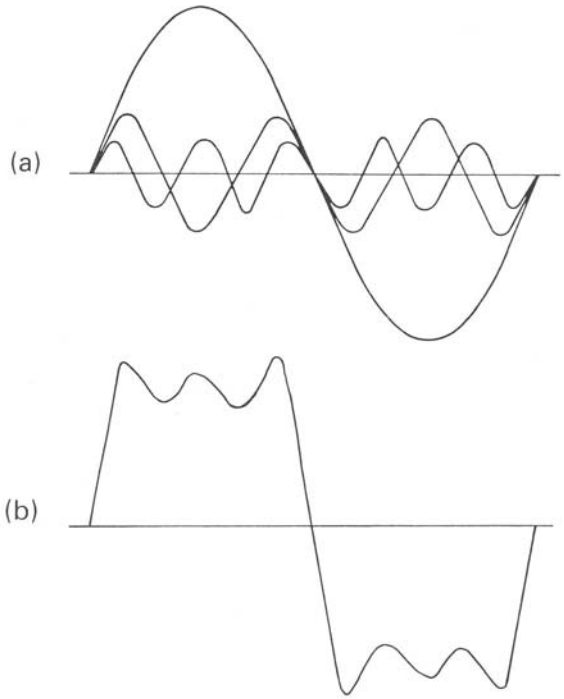
vector representing stimulus contrast

A Computational Model of the Human Visual System

David Marr, 1982: *Vision. A Computational Investigation into the Human Representation and Processing of Visual Information*



Fourier Analysis



Fourier components

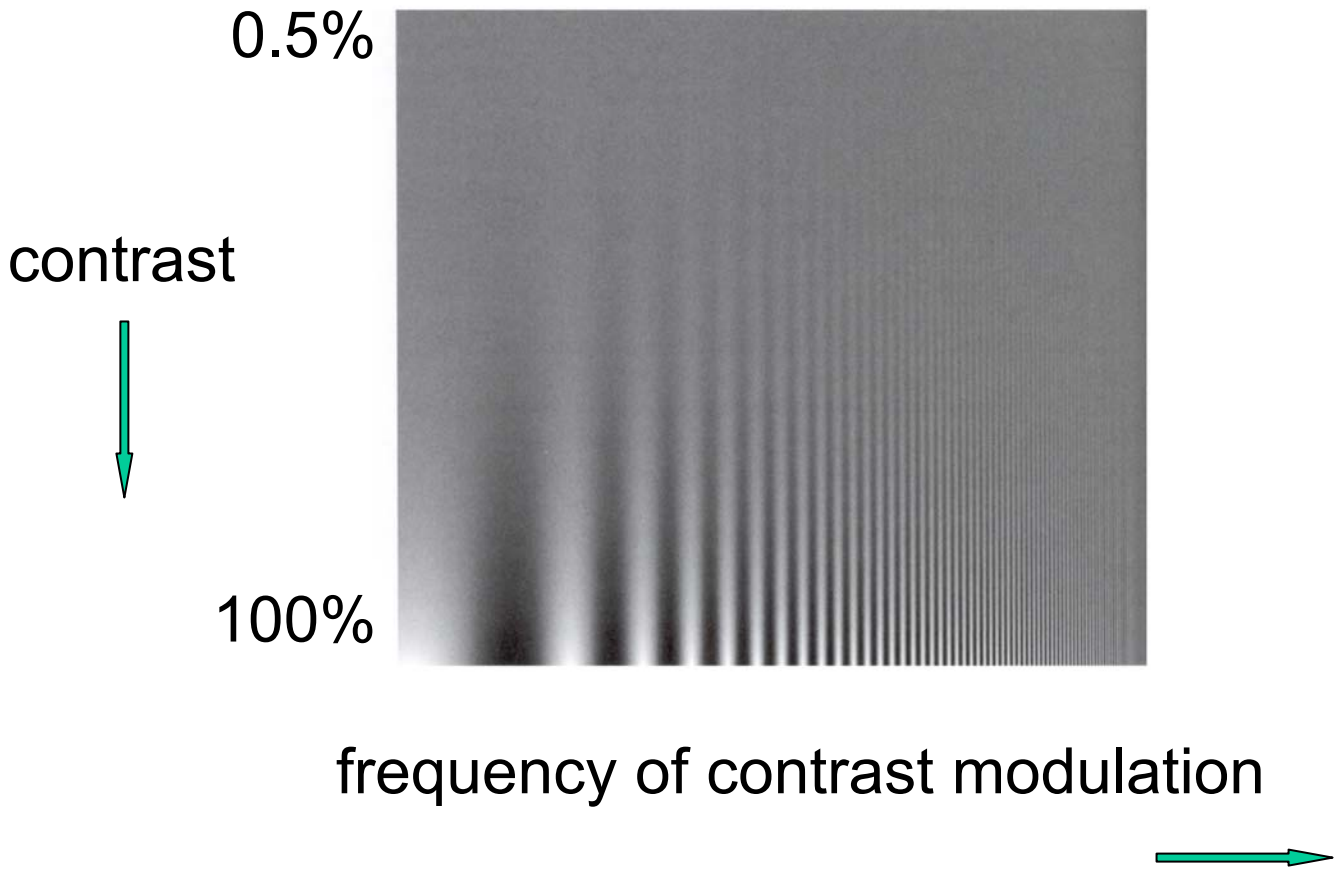
sum of components

A square wave modulation can be decomposed into many sine wave gratings.

Spatial Decomposition

- Every image can be mathematically decomposed into simple patterns (sine wave gratings).
- It is possible study the visual system in response to sine wave gratings.
- We can make predictions about the outcome of our experiments under the assumption that the visual system is a linear system.

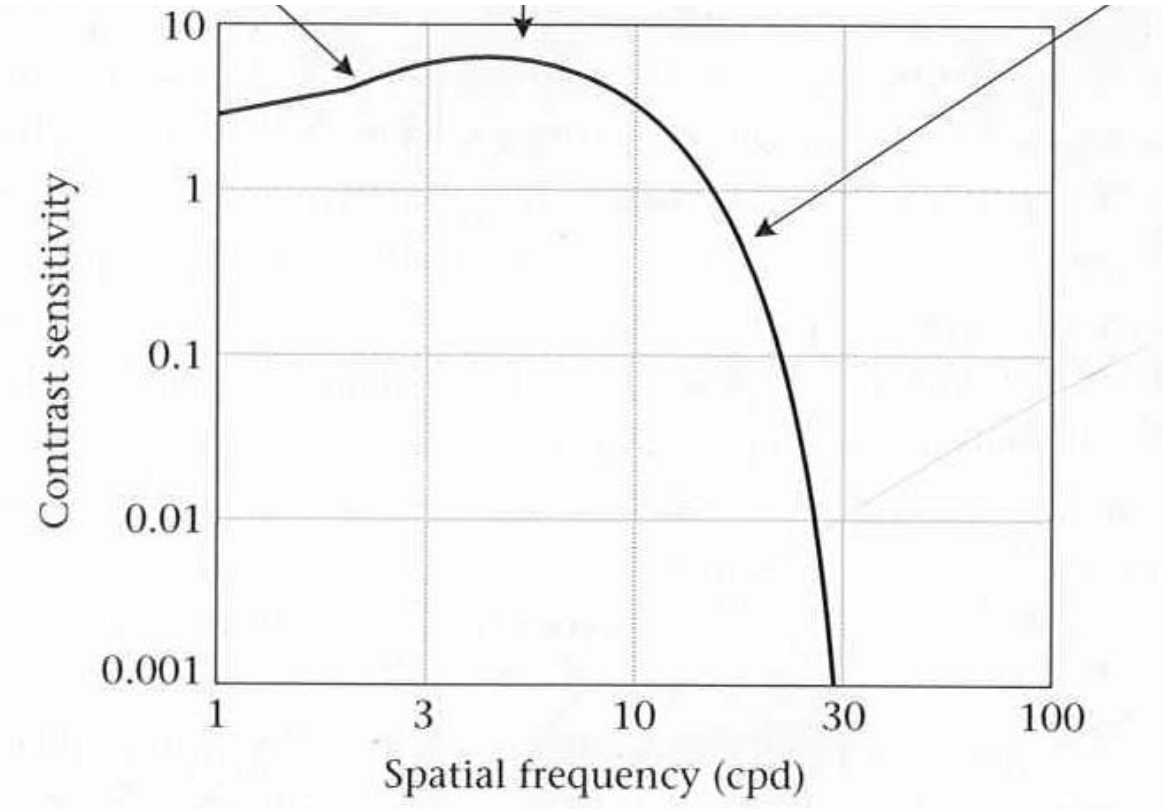
Contrast-Sensitivity Function



Campbell and Robson, 1968, Referat 1

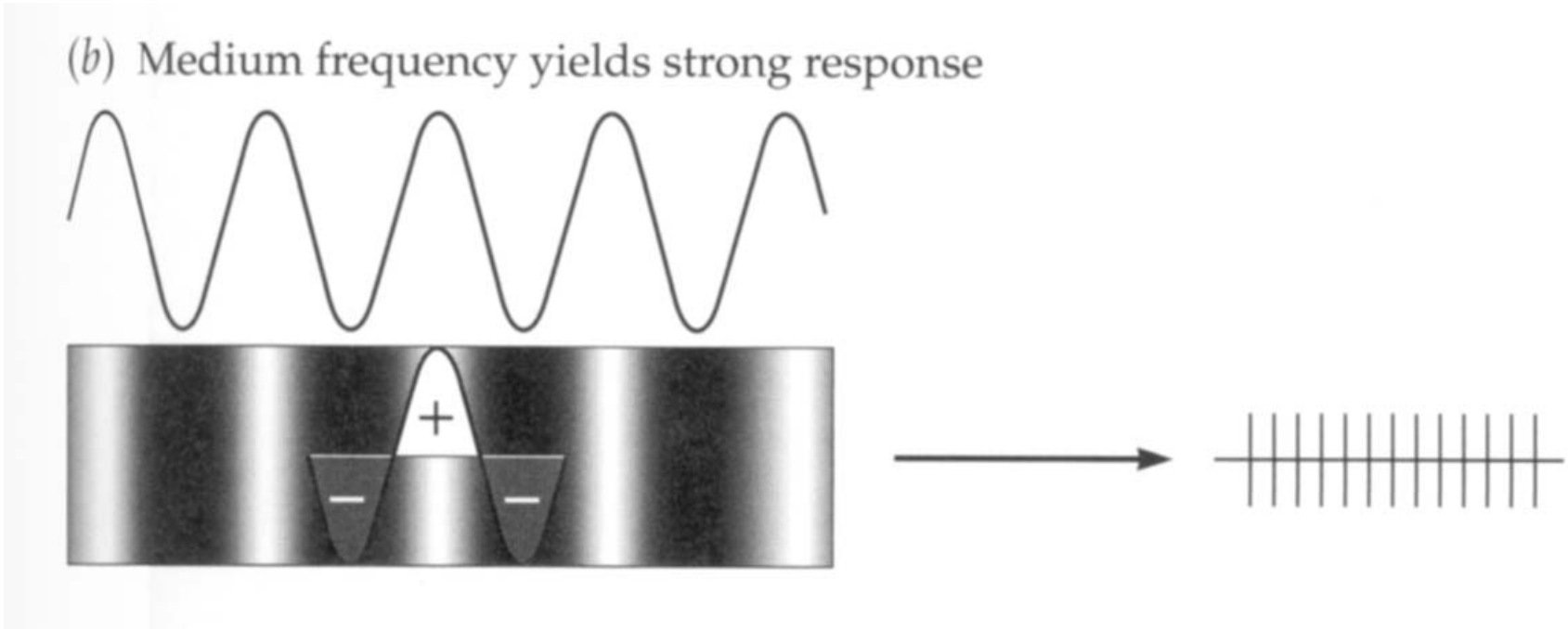
Contrast-Sensitivity Function

Contrast sensitivity: -log c (c: contrast at detection threshold)



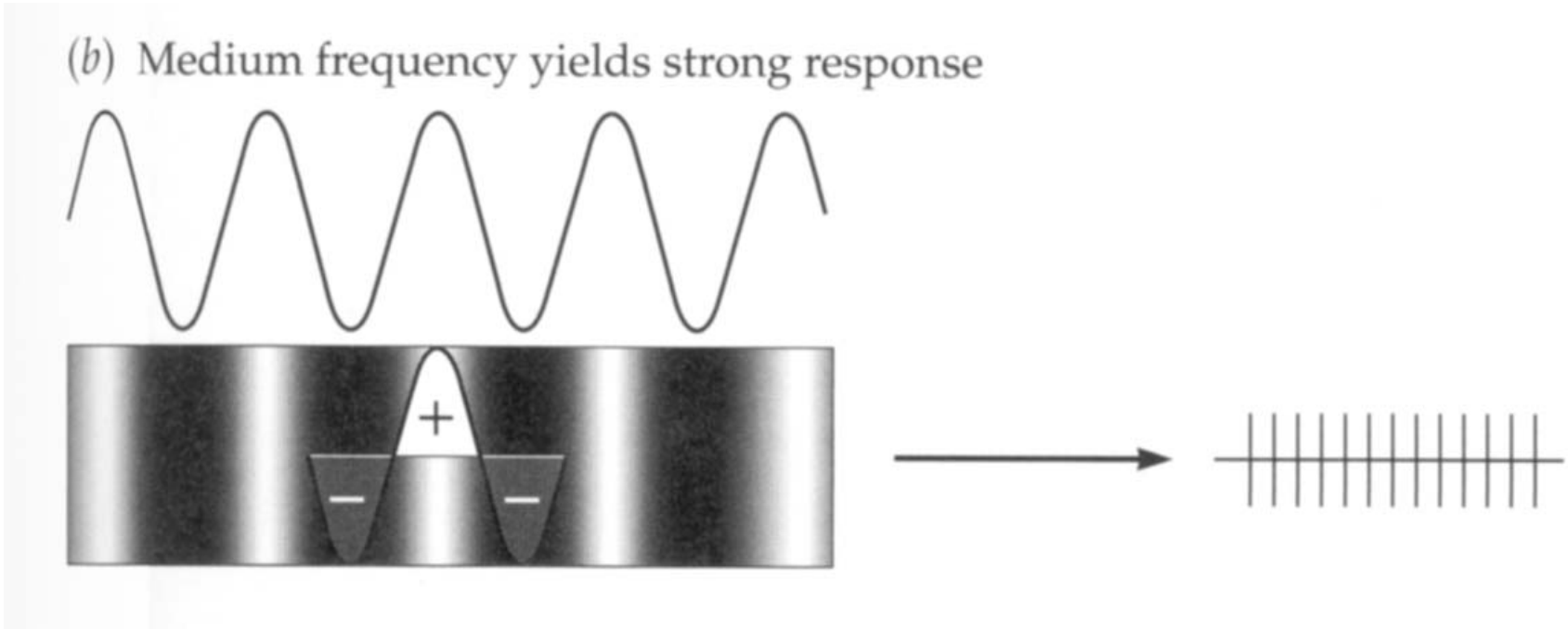
Neuronal Responses to Sine Wave Gratings

center-surround ganglion cell:



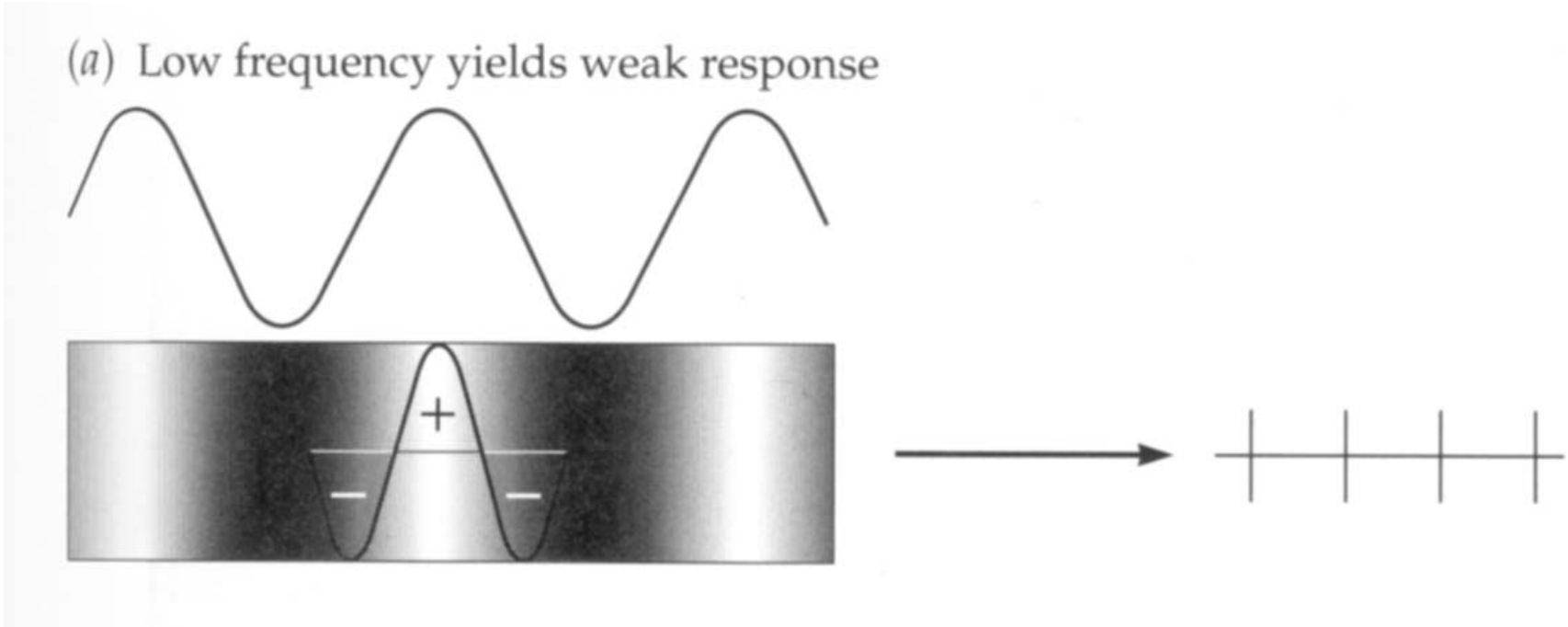
Neuronal Responses to Sine Wave Gratings

center-surround ganglion cell:



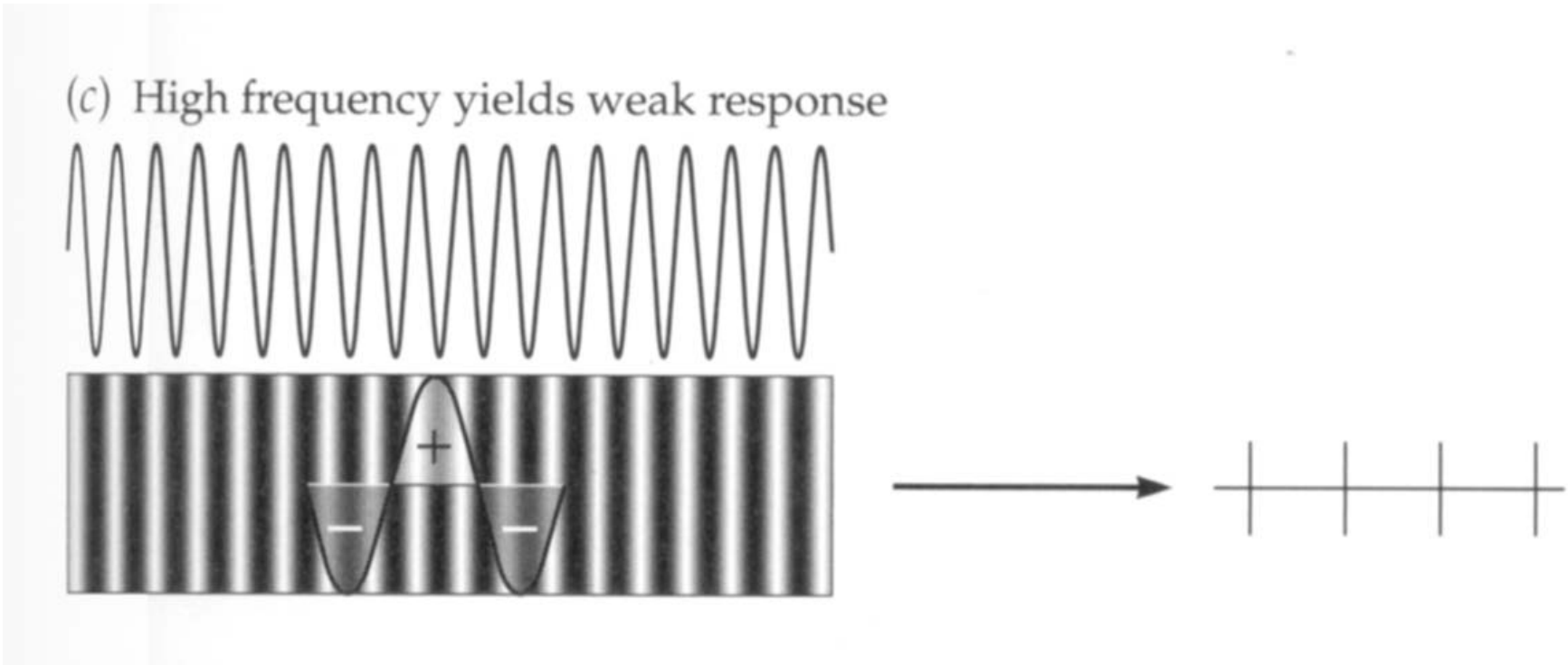
Neuronal Responses to Sine Wave Gratings

center-surround ganglion cell:



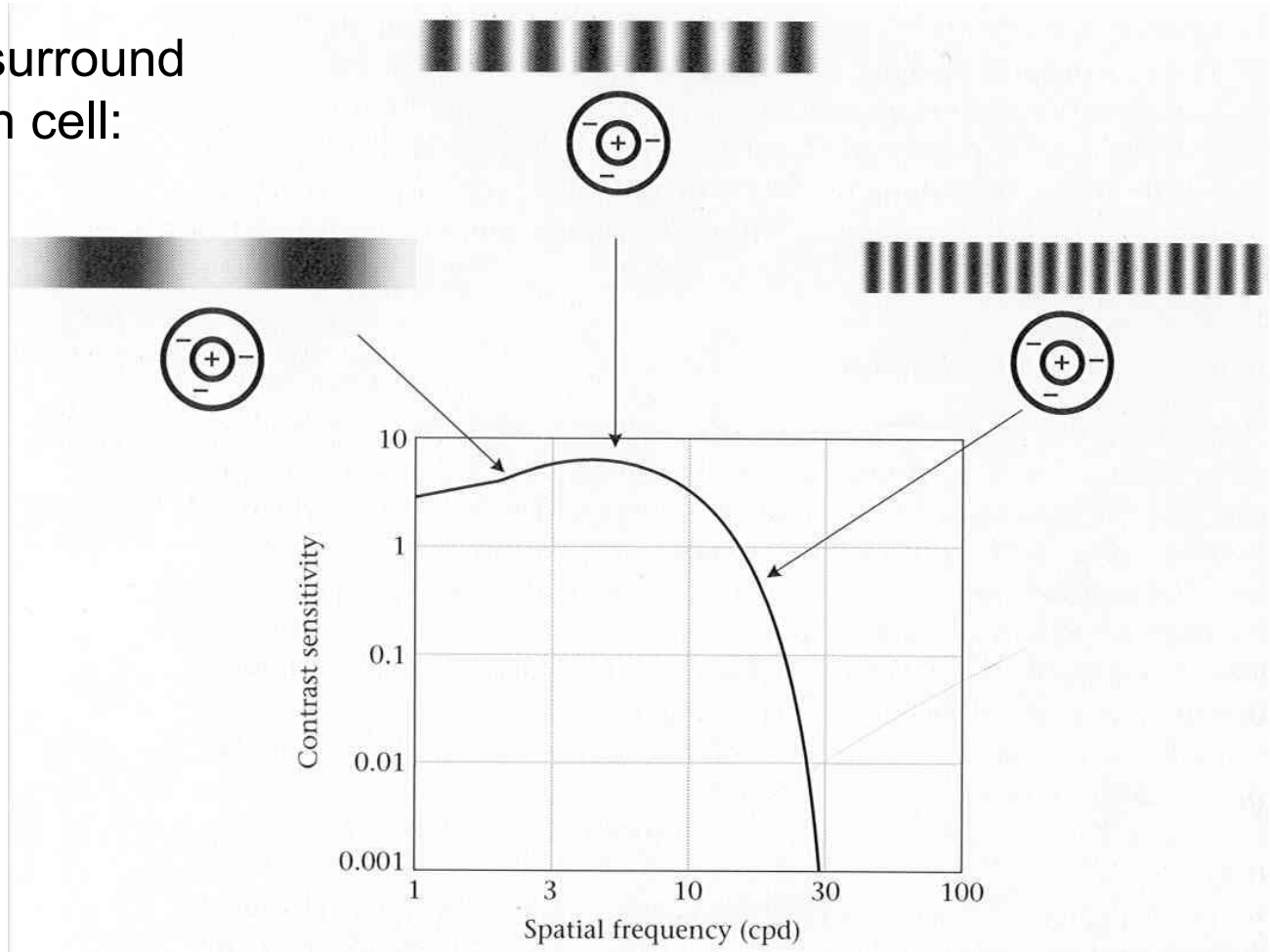
Neuronal Responses to Sine Wave Gratings

center-surround ganglion cell:

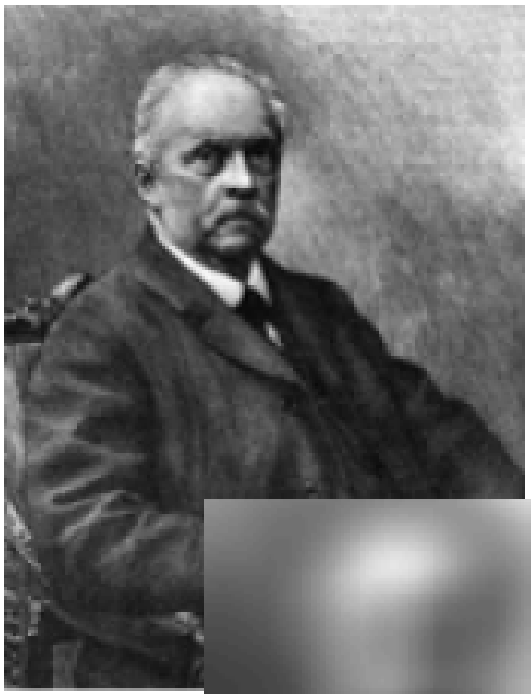


Neuronal Sensitivity to Harmonic Stimuli

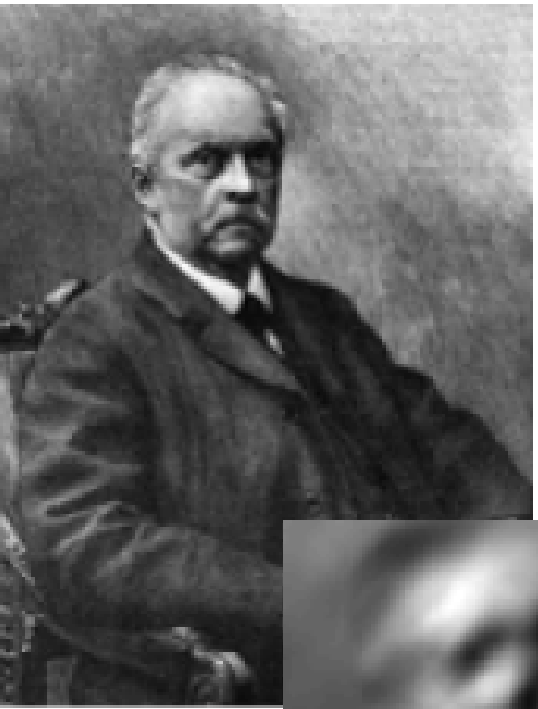
center-surround
ganglion cell:

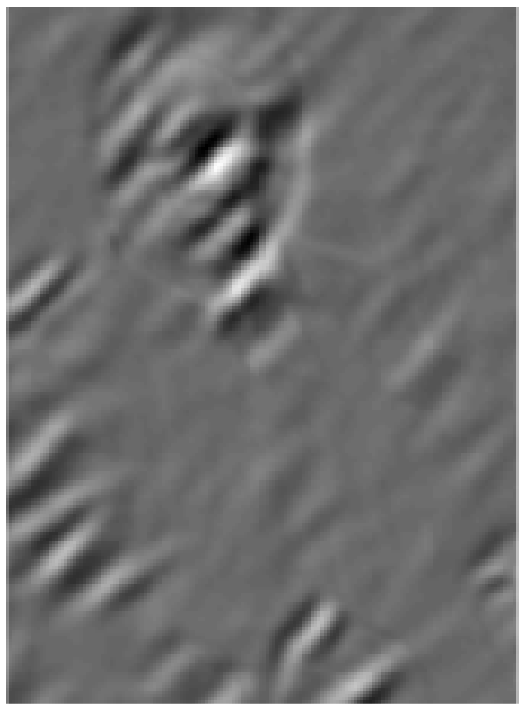


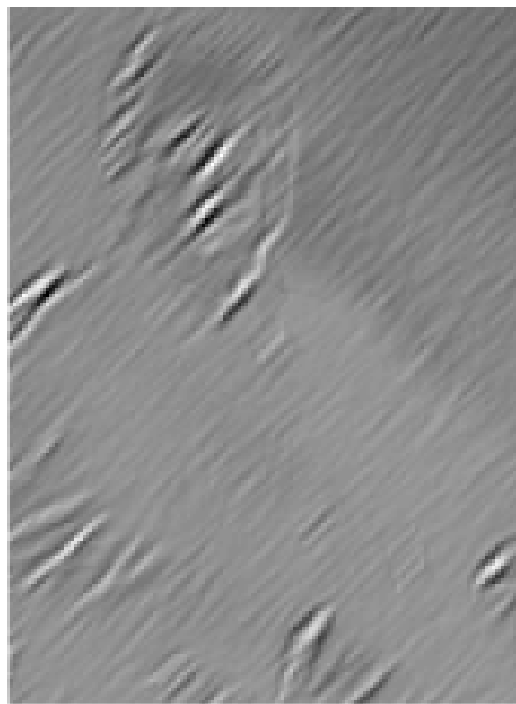
Neuronal Response (LGN)



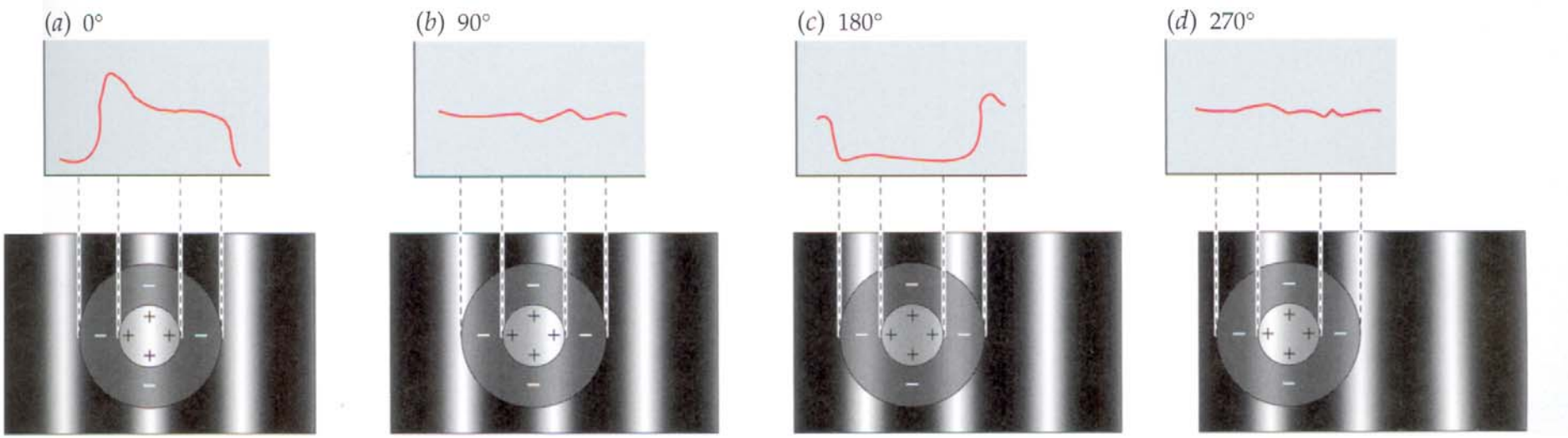
Neuronal Response (V1)



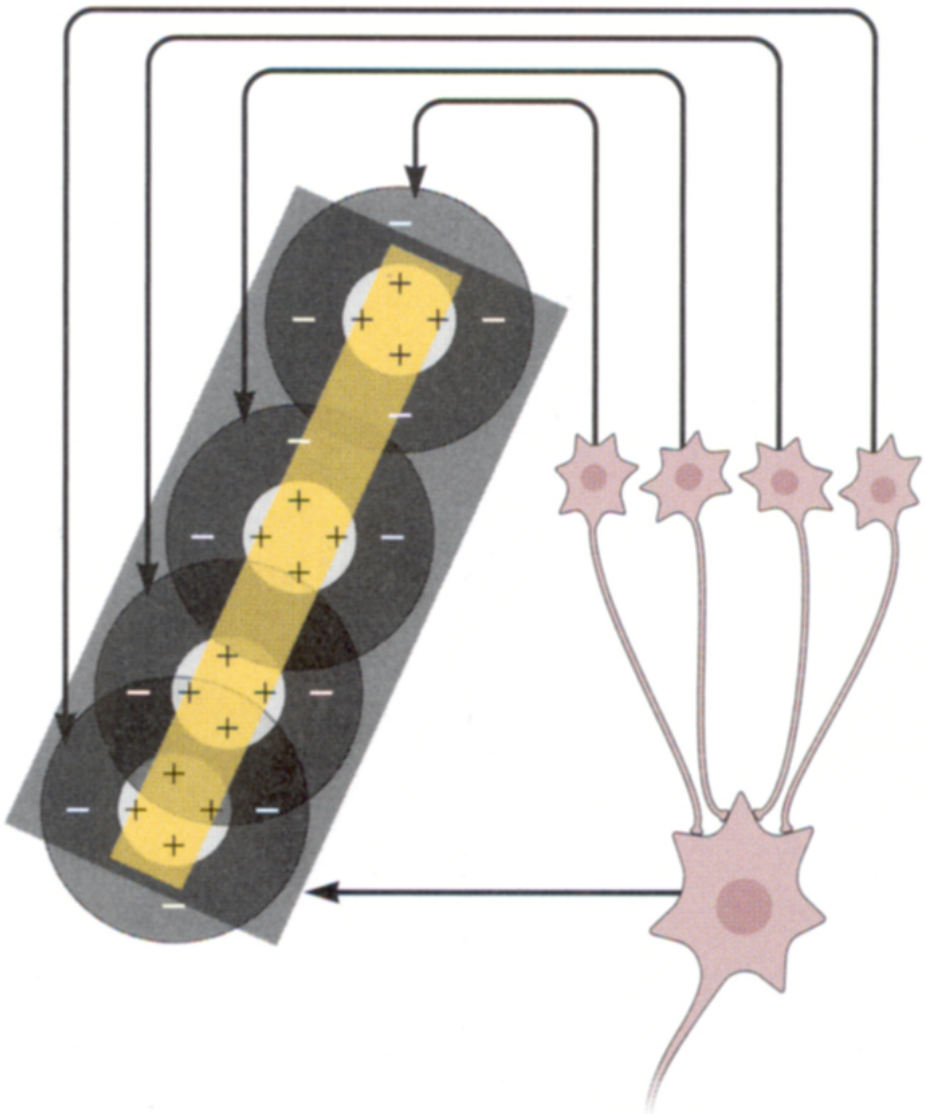




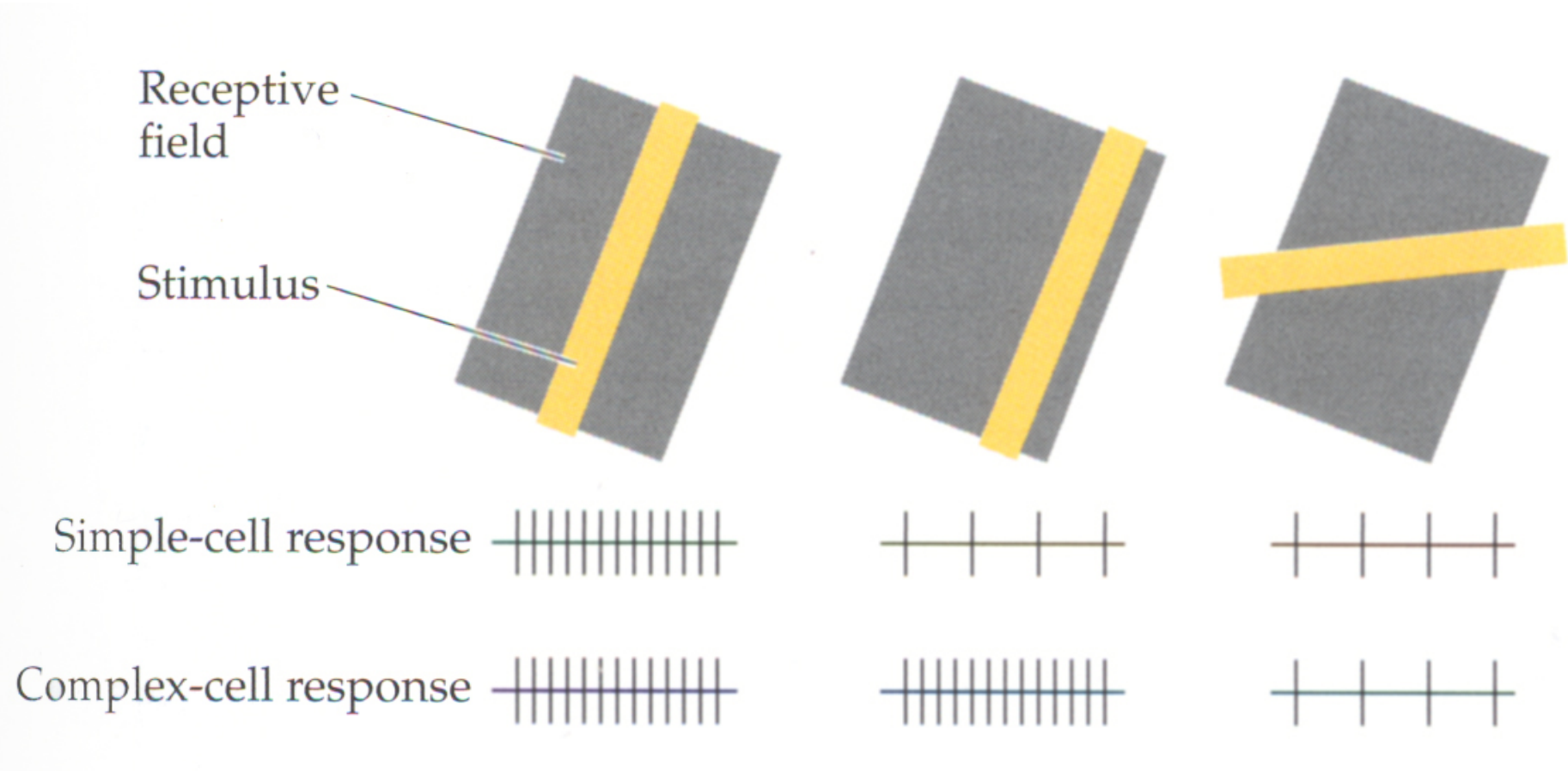
Simple Cells



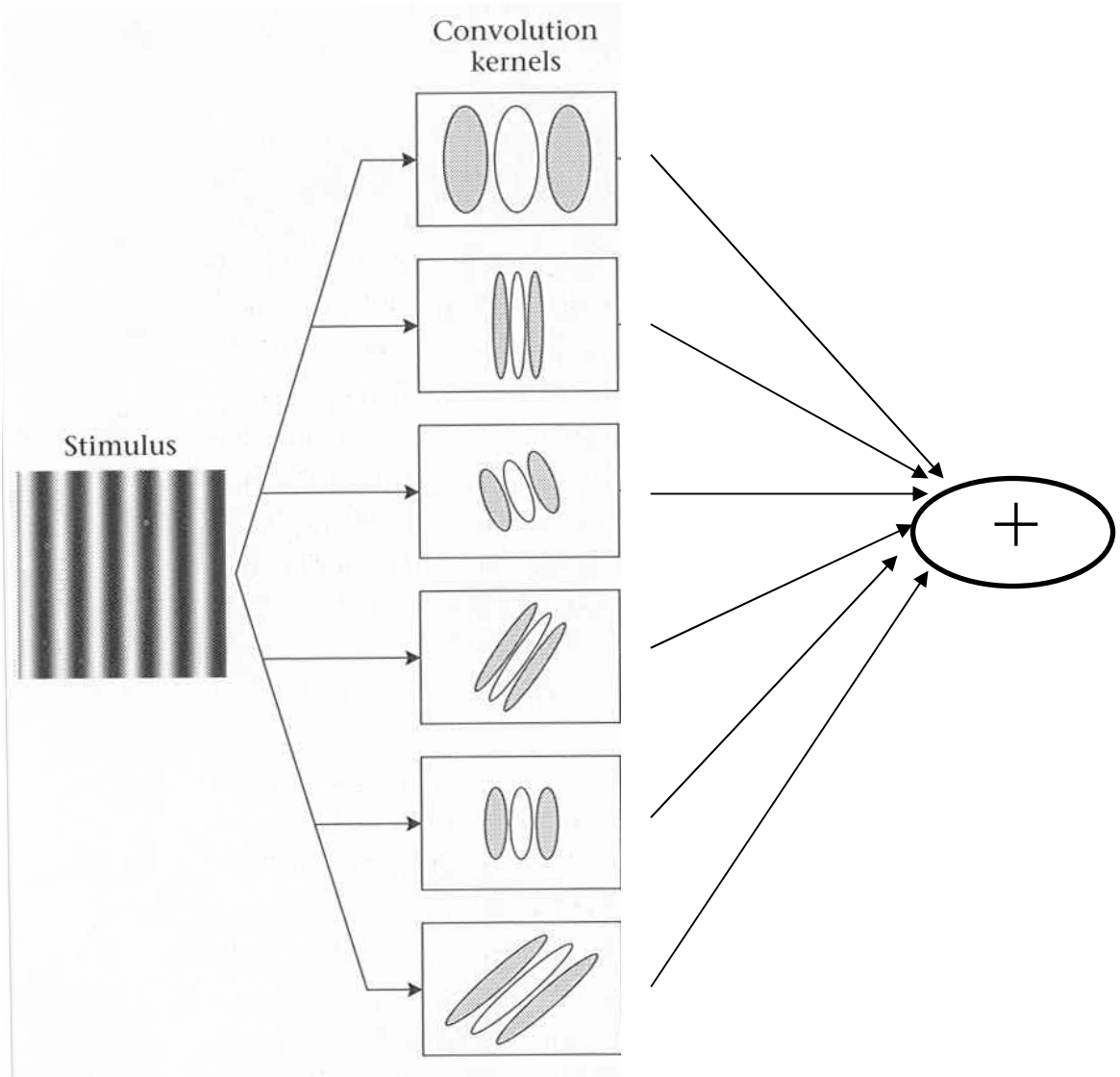
Orientation Selectivity



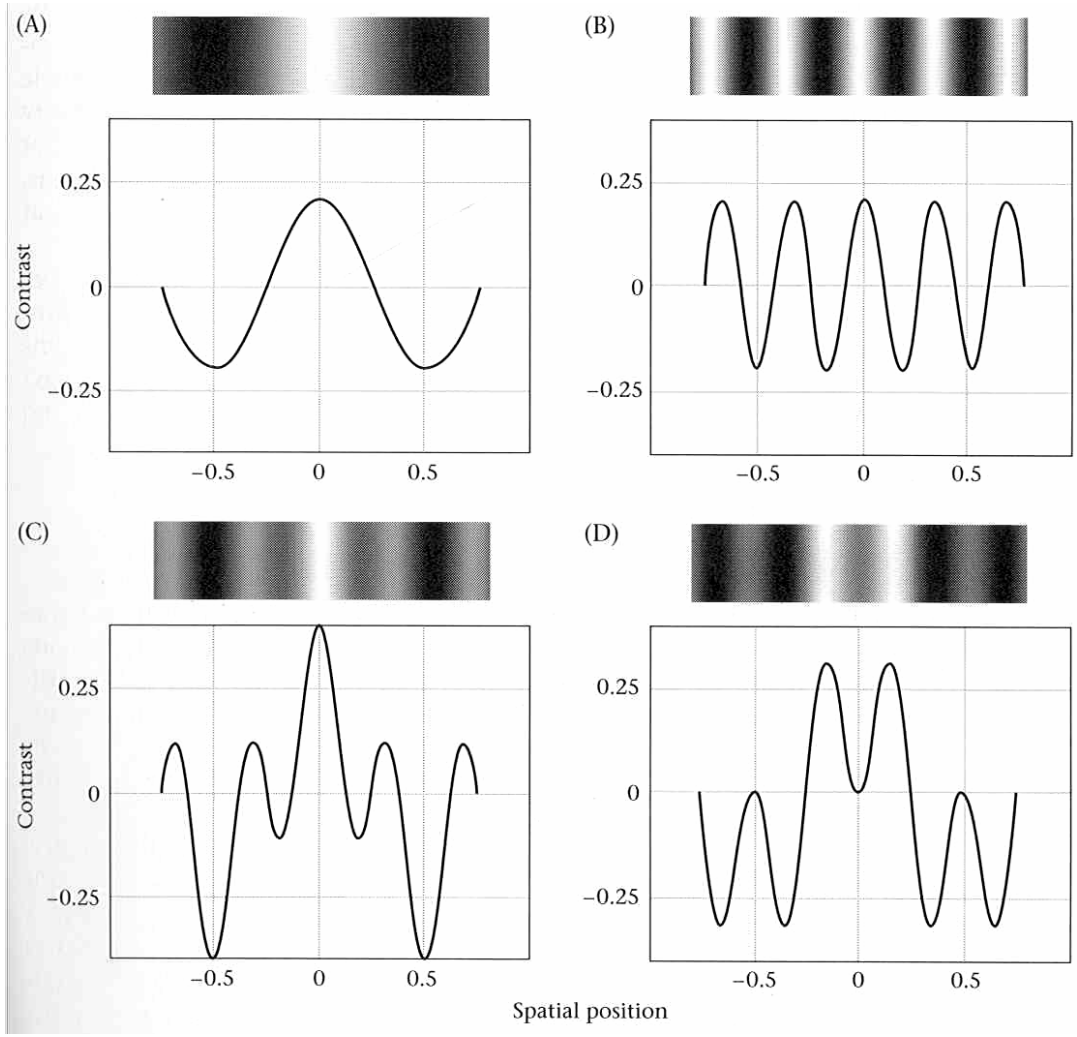
Complex Cells



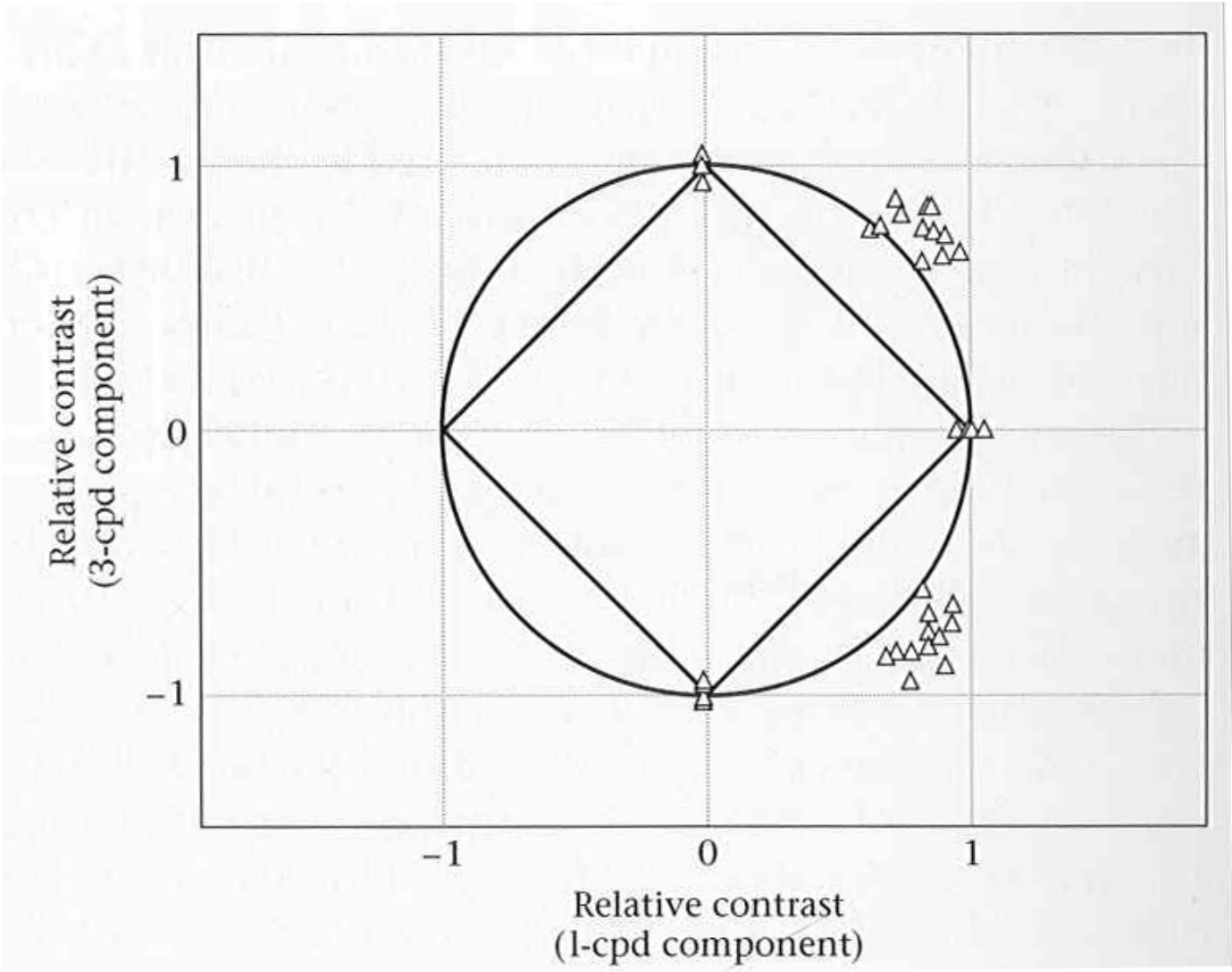
Single-channel Theory



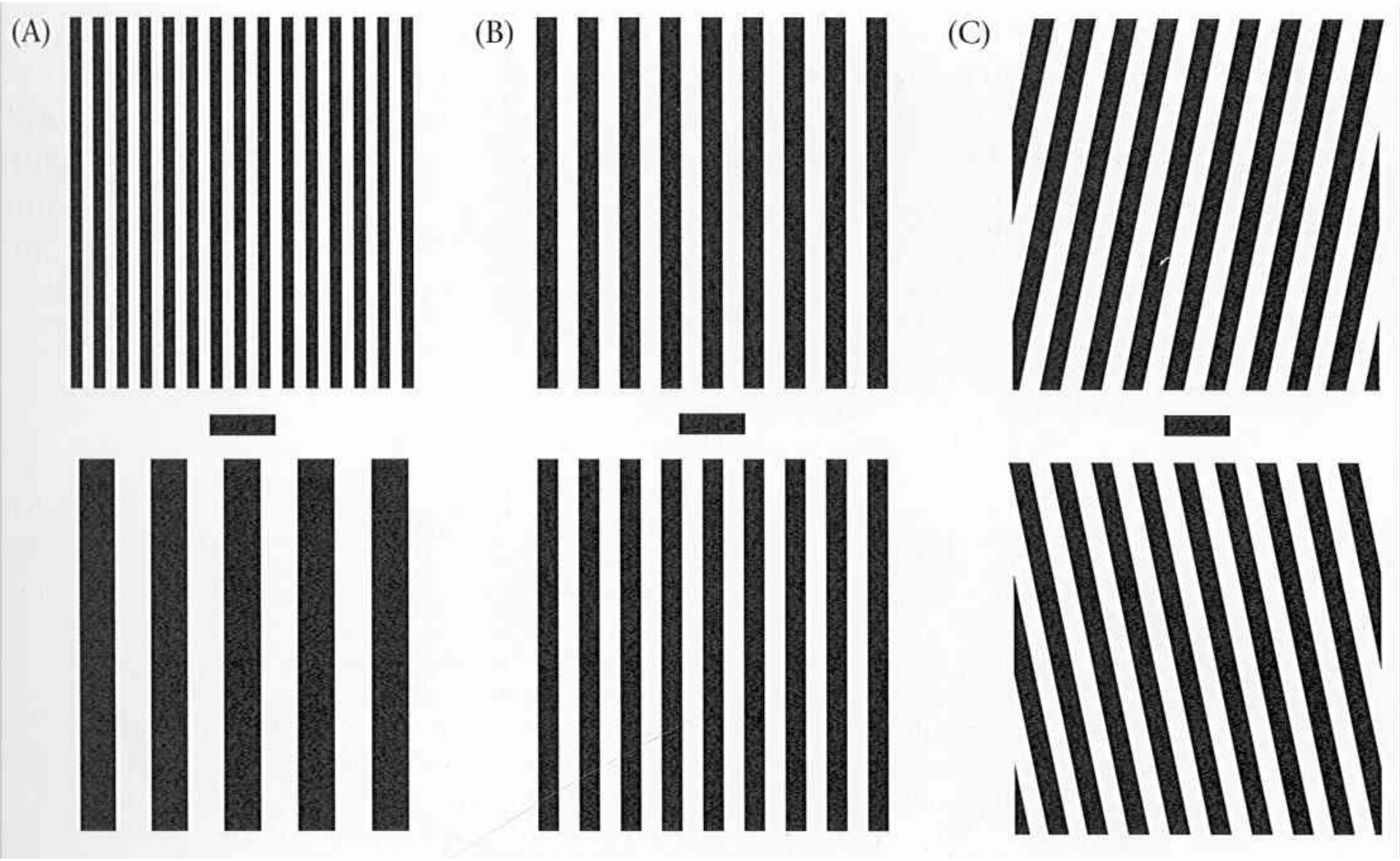
Test of contrast-sensitivity models: Examples of Sine Wave Modulations



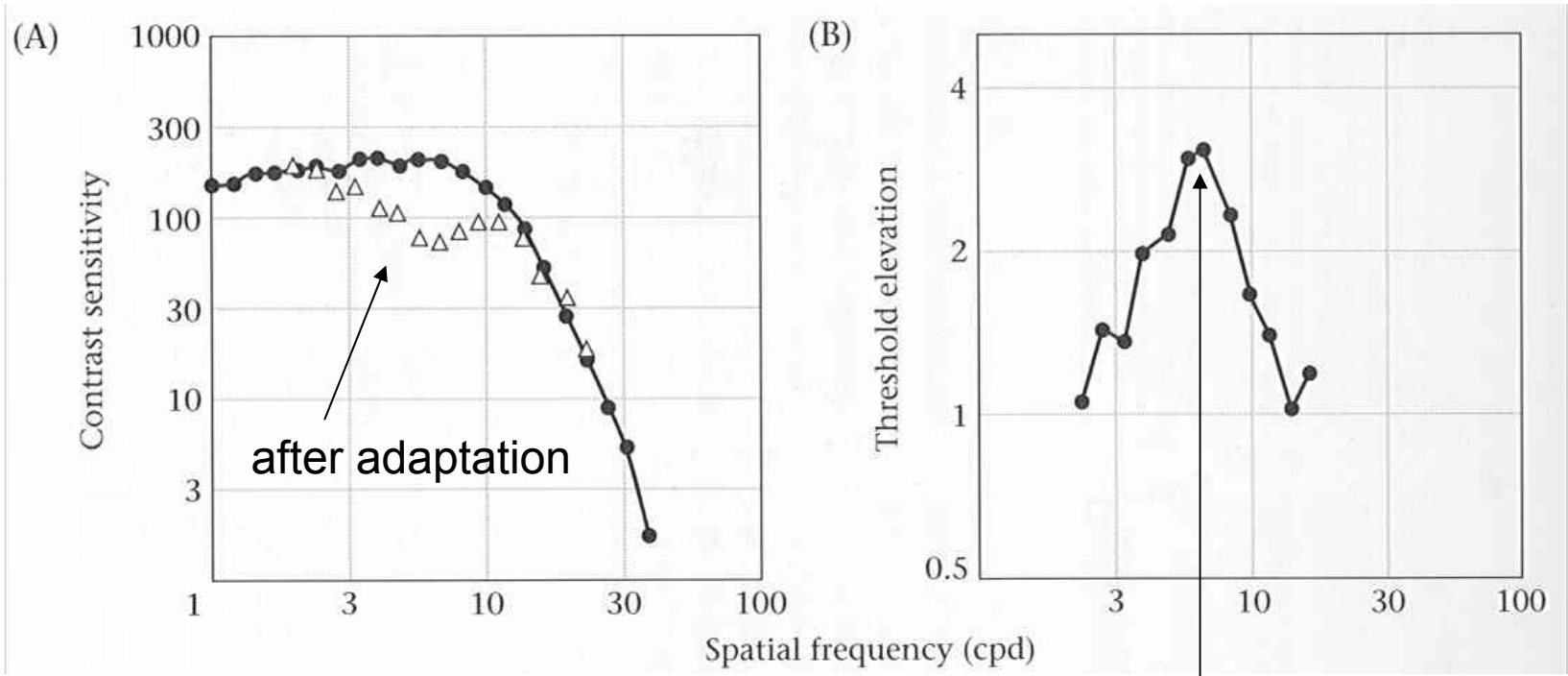
Test of contrast-sensitivity models: Spatial Test-Mixture Threshold



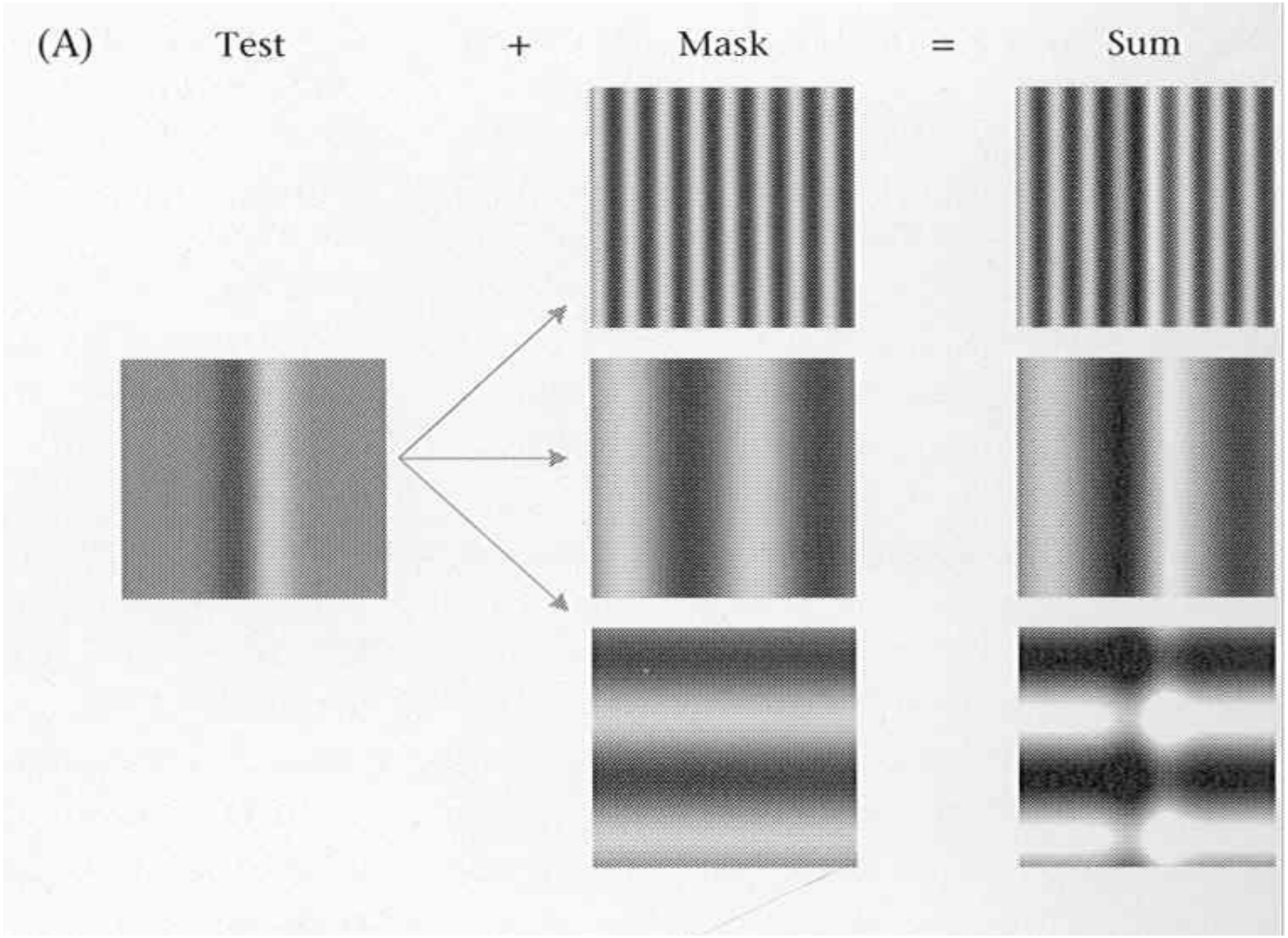
Visual Pattern Adaptation



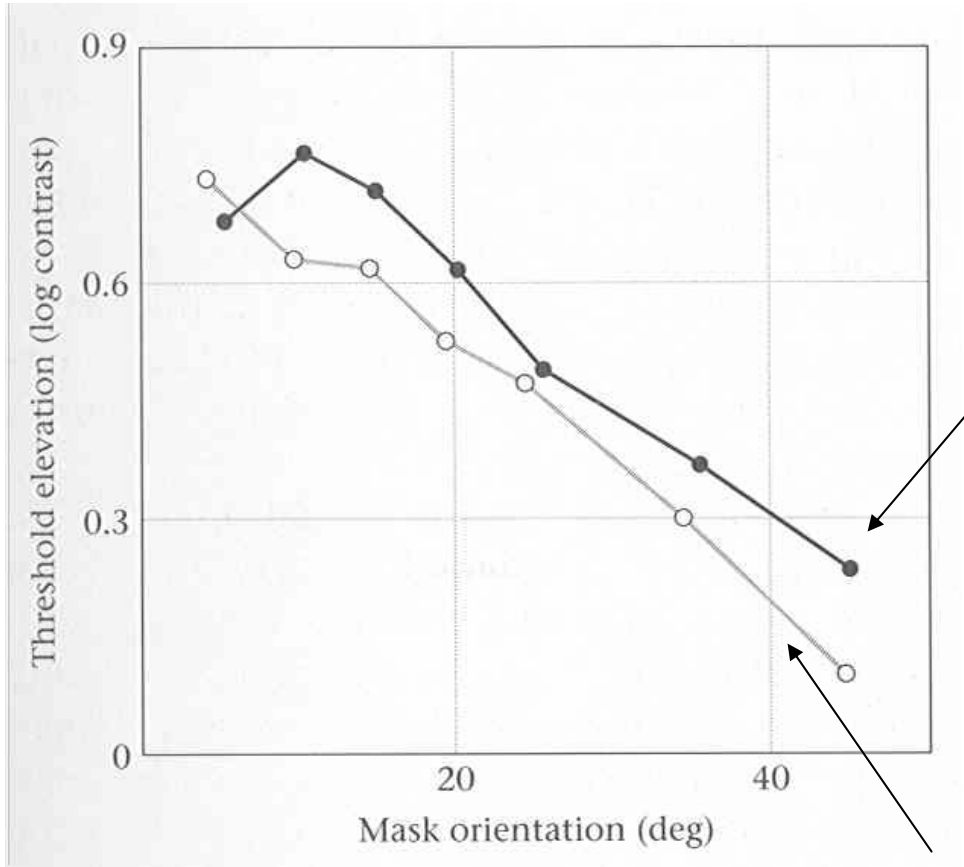
Effects of Pattern Adaptation on the Contrast-Sensitivity Function



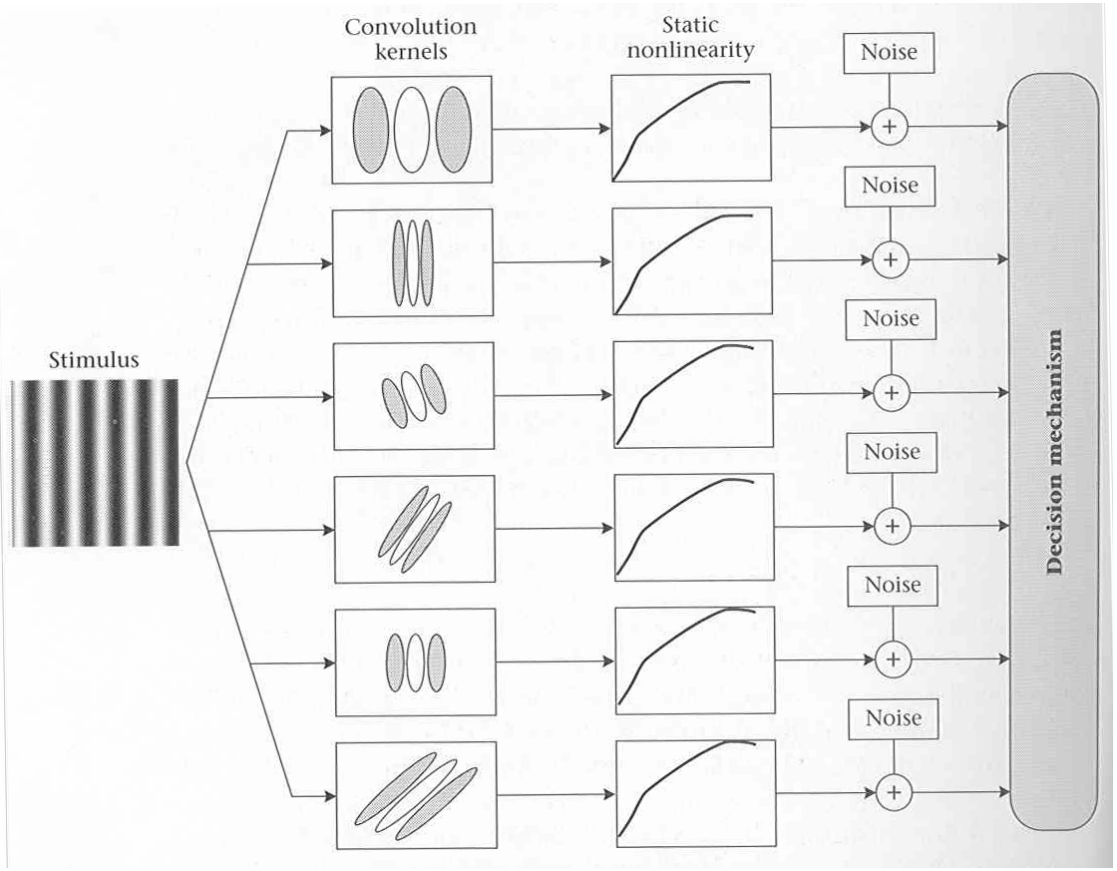
Masking and Facilitation



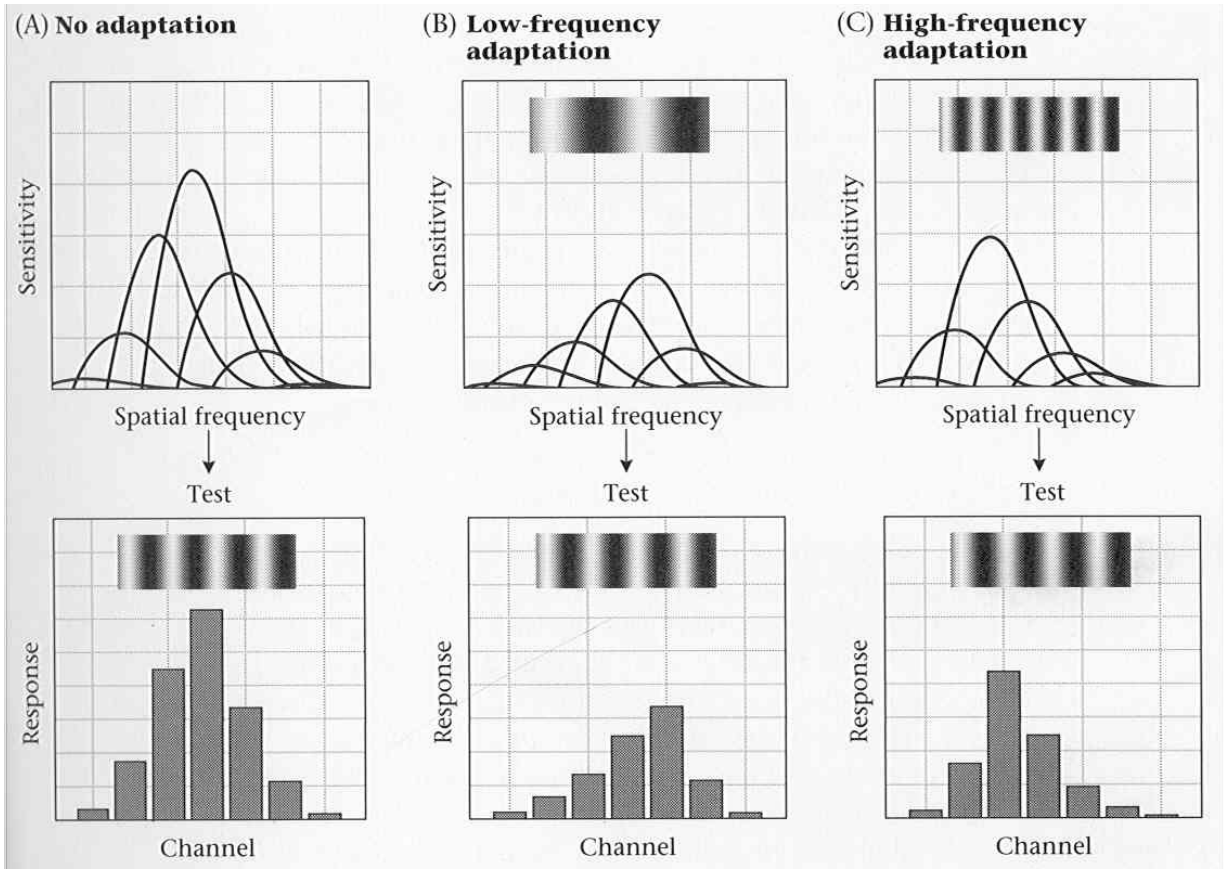
Orientation Tuning in the Masking Experiment



A Multiresolution Model of Spatial Pattern Sensitivity



Evidence for a Multiresolution Model of Spatial Pattern Sensitivity



Conclusion

- The *detection* of patterns/images can be successfully predicted by Multiresolution Theory of spatial frequency channels
- The Multiresolution Theory cannot predict how we *recognize* objects.

Referat 1:

J. Physiol. (1968), **197**, *pp.* 551–566
With 7 text-figures
Printed in Great Britain

APPLICATION OF FOURIER ANALYSIS TO THE VISIBILITY OF GRATINGS

BY F. W. CAMPBELL AND J. G. ROBSON
From the Physiological Laboratory, University of Cambridge

(*Received* 10 *November* 1967)

SUMMARY

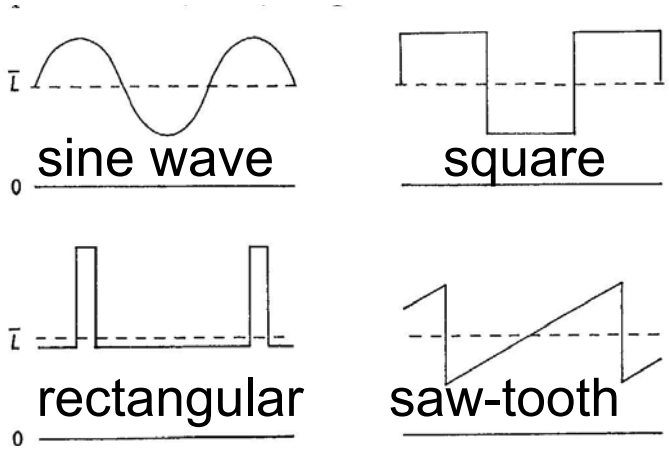
1. The contrast thresholds of a variety of grating patterns have been measured over a wide range of spatial frequencies.

Purpose of study:

- Can simple linear theory be used to study the formation of optical images, i.e. to which extend does the contrast-sensitivity function predict contrast thresholds?
- Experimental hypothesis (as test of linear theory): The visibility of contrast gratings is largely determined by the fundamental Fourier component.

Task:

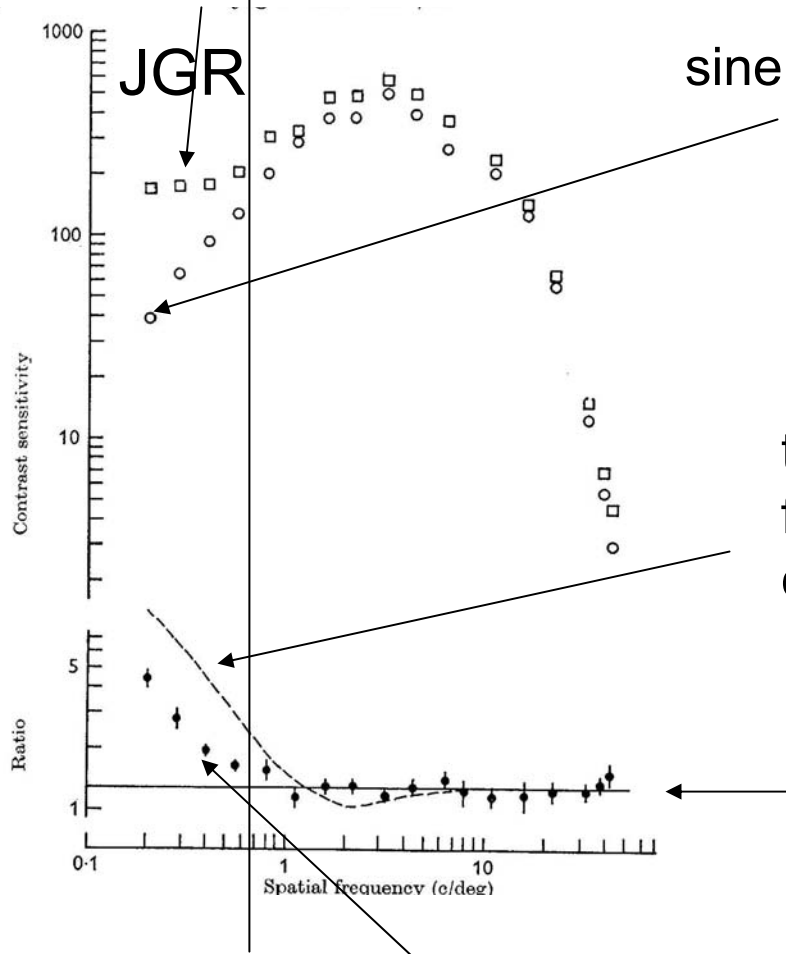
- subjects adjusted contrast of grating of given spatial frequency compared to test stimulus
- 2 subjects
- 4 types of gratings
- monocular viewing
- stimulus presentation with 100 Hz
- 2 viewing distances to compensate for frequency dependent modulation of CRT display



gratings not perceived to be different

Results:

square wave gratings



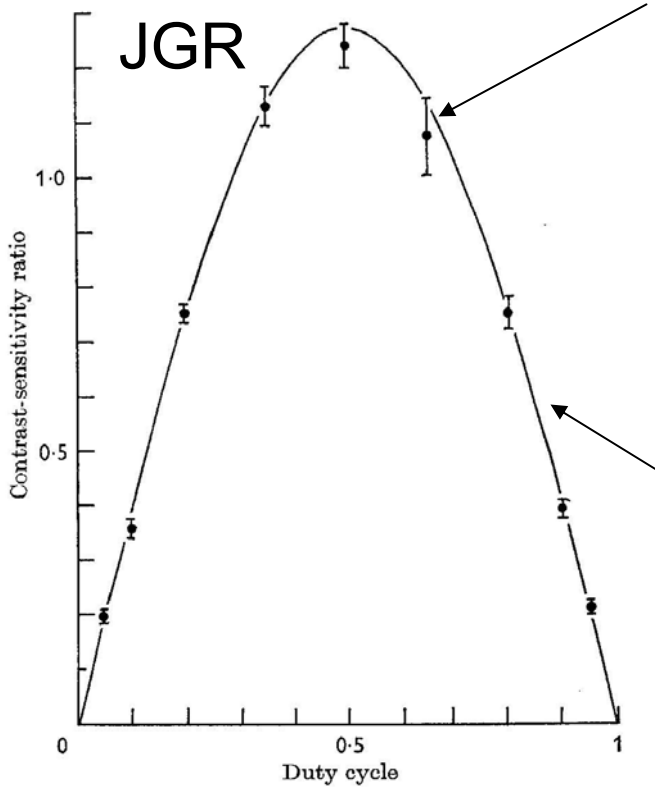
sine wave gratings

theoretical prediction if only fundamental component contributes to visibility

sensitivity ratio at $4/\pi$ (amplitude ratio of fundamental component)

experimental data

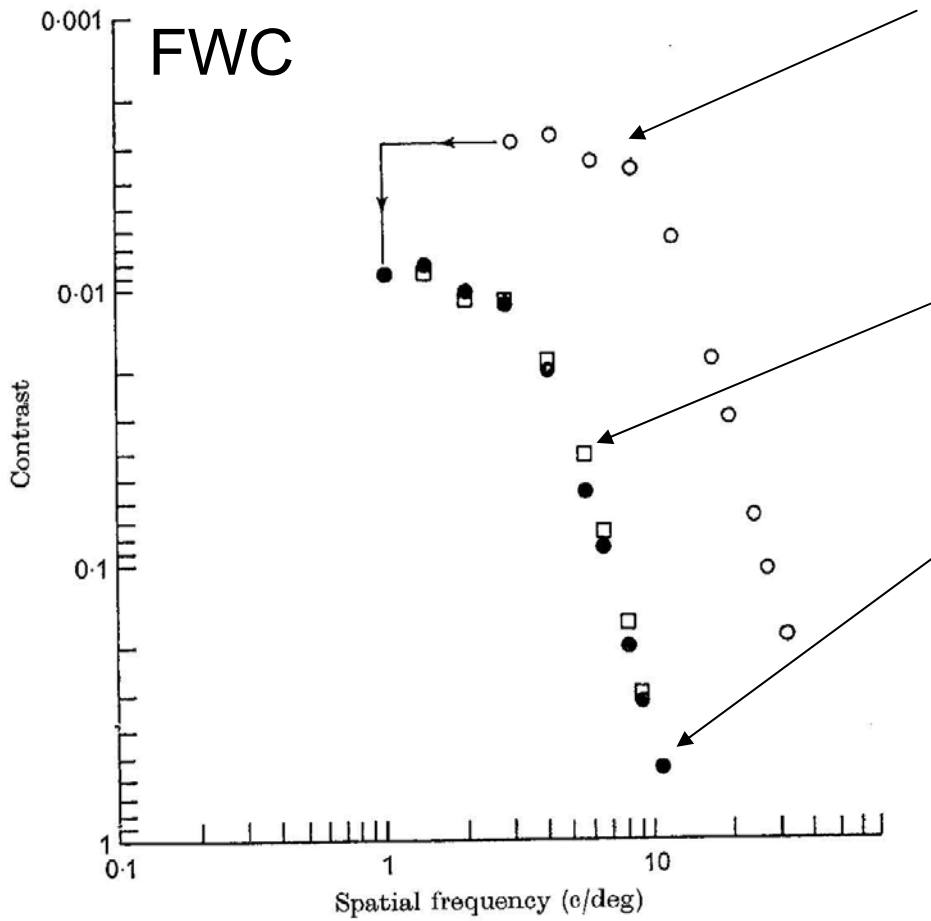
Results:



ratio of threshold contrast for a sine-wave grating to the threshold for a rectangular-wave grating

theoretical prediction if only fundamental component contributes to visibility

Results: simultaneous adjustment of both gratings until patterns can be distinguished



sine wave grating above threshold

square wave grating at threshold

sine wave grating at threshold

More Results:

- Square-wave gratings are perceived to be different from sine-wave gratings when the third harmonic reaches own threshold (and doesn't contribute below threshold).
- Same experimental evidence from saw tooth gratings

  $\Rightarrow$ Evidence for independent thresholds for the different frequency channels
- However: higher harmonic components contribute less than expected

  $\Rightarrow$ Simple peak detector mechanism cannot explain the whole visual system

Referat 2:

Vision Res. Vol. 15, pp. 887–897. Pergamon Press 1975. Printed in Great Britain.

SOME EXPERIMENTS BEARING ON THE HYPOTHESIS THAT THE VISUAL SYSTEM ANALYSES SPATIAL PATTERNS IN INDEPENDENT BANDS OF SPATIAL FREQUENCY[1]

G. BRUCE HENNING,* B. GEVENE HERTZ† and D. E. BROADBENT*

*Department of Experimental Psychology, South Parks Road, Oxford OX1 3UD, England; and
†The Biomedical Engineering Center, Northwestern University, Evanston, Illinois 60201, U.S.A.

(*Received* 29 *August* 1974; *in revised form* 25 *November* 1974)

Abstract -Gratings with three sinusoidal components of high spatial frequency are shown to interact with a sinusoidal grating two octaves lower in frequency. This finding is inconsistent with the hypothesis that the visual system analyses spatial patterns in independent narrowly-tuned bands of spatial frequency.

Purpose of study:

Test of Campbell & Robson's hypothesis (1968) that the linear system is composed of many independent linear mechanisms ("channels").

Task:

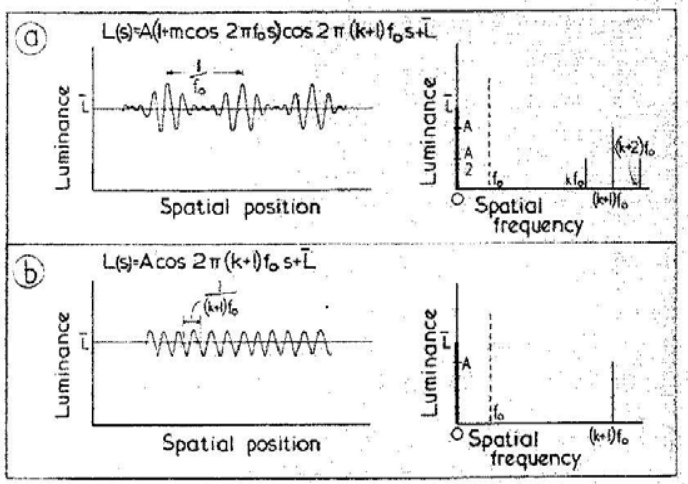
- series of 4 experiments
- 2AFC forced-choice grating detection experiment:
  subsequent stimulus presentation of 2 gratings
  presentation of stimulus for 1sec, ISI = 600 ms
  time interval for response: 750 ms
  2 observers
- monocular viewing conditions

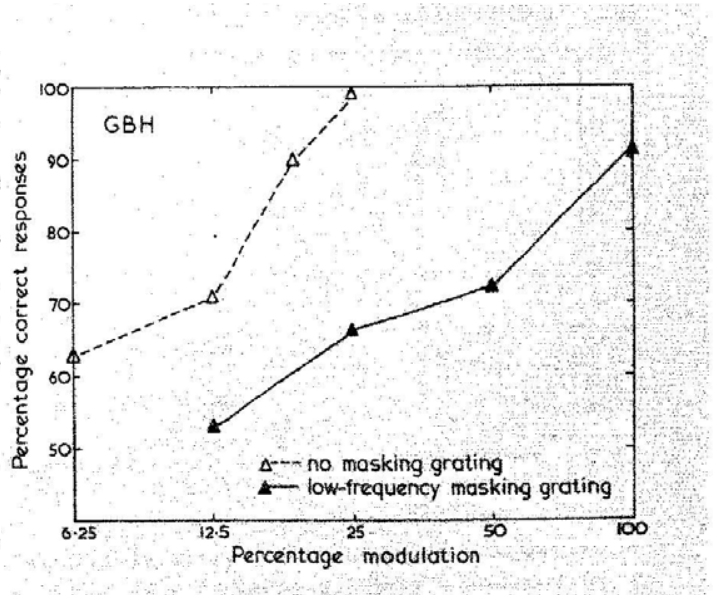
Results: Exp. 1, masking with low-frequency complex grating

Task: detection of contrast modulation

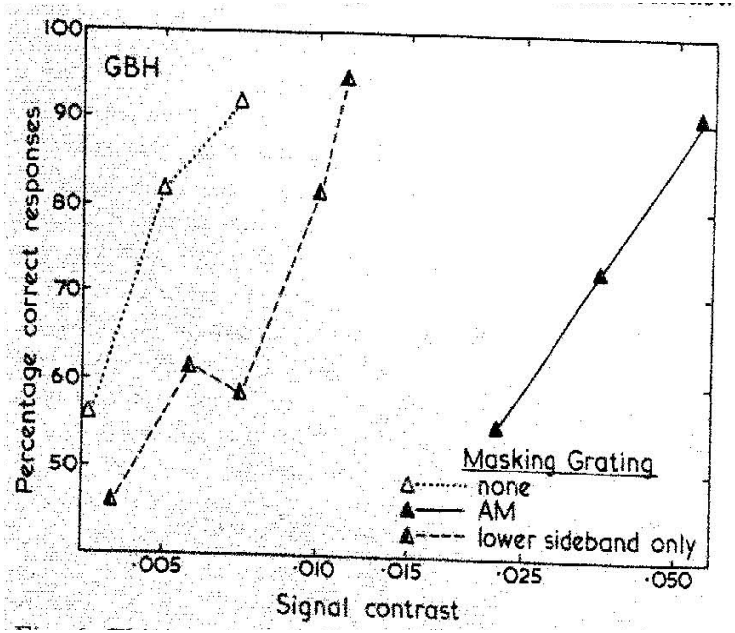
Stimulus A

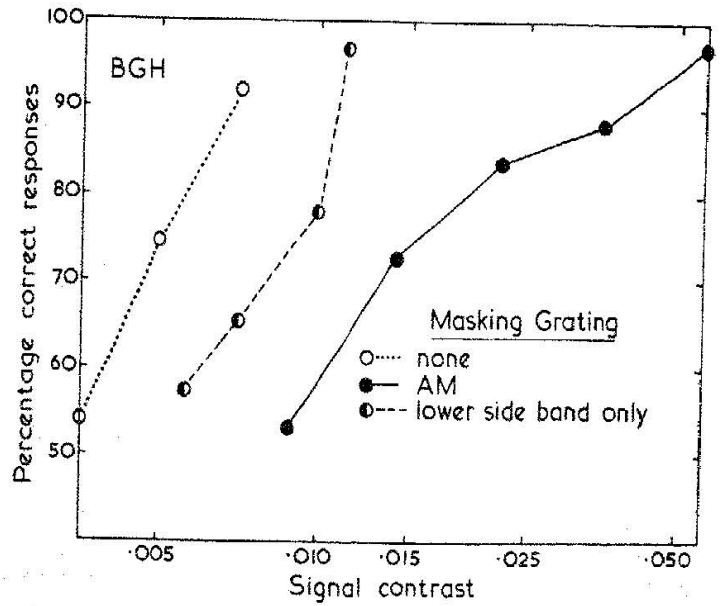
Stimulus B



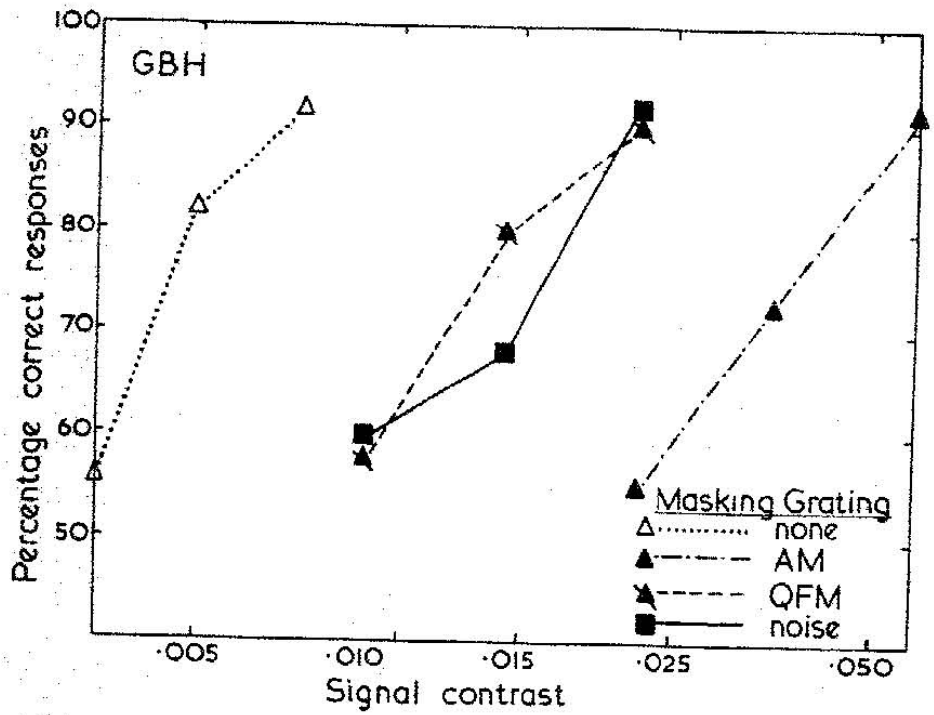


Results: Exp. 2, masking with high-frequency complex grating

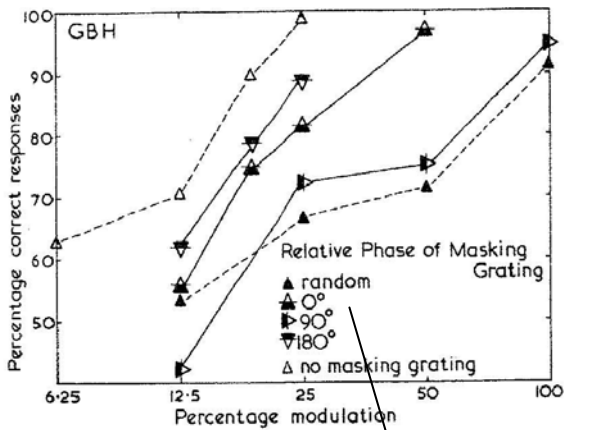




Results: Exp. 3, masking with high-frequency phase-shifted complex grating



Results: Exp. 4, masking with low-frequency complex grating under variation of fixed phase



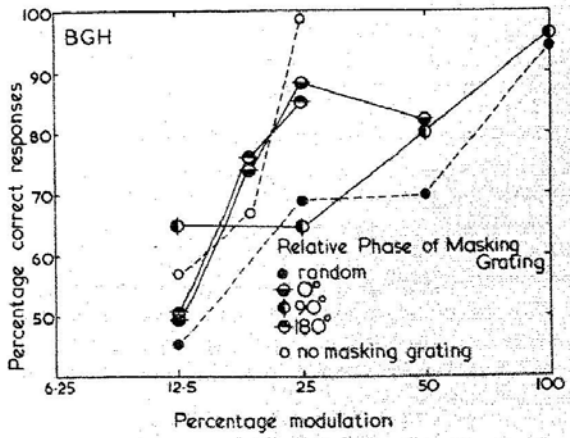


Fig. 12. This shows results for observer BGH in the conditions outlined in Fig. 11.

fixed during blocks of 50 trials

Conclusion:

Detectability and discriminability of spatial patterns cannot be predicted from a knowledge of their Fourier spectra – even for components with widely differing spatial frequencies.

“This is disappointing; a crude spatial-frequency analysis in broadly tuned linear and independent channels would have provided an attractive and simple model of human pattern recognition.”