

Perception: Psychophysics and Modeling

06 | Spatial Vision II

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Supplementary Literature

Carter, B. E. and Henning, G. B. (1971). The detection of gratings in narrow-band visual noise. *Journal of Physiology*, 219(2):355–365.

Henning, G. B., Hertz, B. G., and Broadbent, D. E. (1975). Some experiments bearing on the hypothesis that the visual system analyzes patterns in independent bands of spatial frequency. *Vision Research*, 15:887–899.

Adelson, E. H. and Bergen, J. R. (1991). The plenoptic function and the elements of early vision. In Landy, M. S. and Movshon, J. A., editors, *Computational Models of Visual Processing*, pages 3–20. MIT Press.

Wolfe, J.M. et al. (2015). “Spatial Vision: From Spots to Stripes”, ch. 3, pp. 53–88. *Sensation and Perception*. 4th edition, Sunderland, Massachusetts: Sinauer.
10 Exemplare in der Lehrbuchsammlung Wilhelmstraße, psy A 1220 Aufl.4(2015)
1 Exemplar im FB Psychologie, AG Evol. Kogn., \$B21/51

The advent of modern spatial vision

Detectability of periodic patterns can be predicted from their Fourier spectrum.
(Campbell & Robson, 1968)

Detection of compound patterns with sufficiently different spatial frequency is independent of local phase (“summation experiments”).
(Graham & Nachmias, 1971)

Adaptation is spatial frequency selective.
(Blakemore & Campbell, 1969)

Contrast discrimination may be better than detection.
(Nachmias & Sansbury, 1974)

Uncertainty experiments—detection of multiple signals.
(Davis, Kramer & Graham, 1983)

Perception & Psychophysics
 1983, 33 (1), 20-28

Uncertainty about spatial frequency, spatial position, or contrast of visual patterns

ELIZABETH T. DAVIS, PATRICIA KRAMER, and NORMA GRAHAM
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Prevalent theories of pattern vision postulate mechanisms selectively sensitive to spatial frequency and position but not to contrast. Decreased performance in the detection of visual stimuli was found when the observer was uncertain about the spatial frequency or spatial position of a patch of sinusoidal grating but not when he was uncertain about contrast. The uncertainty effects were consistent with multiple-band models in which the observer is able to monitor perfectly all relevant mechanisms. Performance deteriorates when the observer must monitor more mechanisms, because these mechanisms are noisy and give rise to false alarms. This consistency is further evidence that the spatial-frequency and spatial-position mechanisms are noisy, a conclusion previously suggested by the “probability summation” demonstrated in the thresholds for compound stimuli. Somewhat paradoxically, the Quick pooling model, which quantitatively accounts for the amount of probability summation in pattern thresholds, predicts no effects of uncertainty. It cannot, therefore, be strictly correct.

Current theories of pattern vision assume the existence of mechanisms (often called channels) selectively sensitive to different spatial frequencies and also of mechanisms selectively sensitive to different spatial positions. A possible physiological substrate for a spatial-frequency channel is an array of neurons having receptive fields all of the same size and orientation but located at different positions within the visual field. A possible physiological substrate for a mechanism sensitive to a particular spatial position is the set of receptive fields located at that position. (See Graham, 1981, for a review.)

A particular quantitative version of this theory has been extremely successful in predicting the thresholds for a wide variety of patterns (e.g., Bergen, Wilson, & Cowan, 1979; Graham, 1977; Graham, Robson, & Nachmias, 1978; Mostafavi & Sakrison, 1976; Quick, Mullins, & Reichert, 1978; Robson & Graham, 1981; Watson, 1982; Wilson & Bergen, 1979). Although a name for this model has not become standard, we will call it the Quick pooling model since its current use in vision originates with Quick (1974) and it is much quicker to use than alternative models.

The Quick pooling model, as derived from assumptions of independent variability in the responses of each of the multiple mechanisms, is the pure form of a high-threshold model in which the possibility of a false alarm in any mechanism is actually zero.

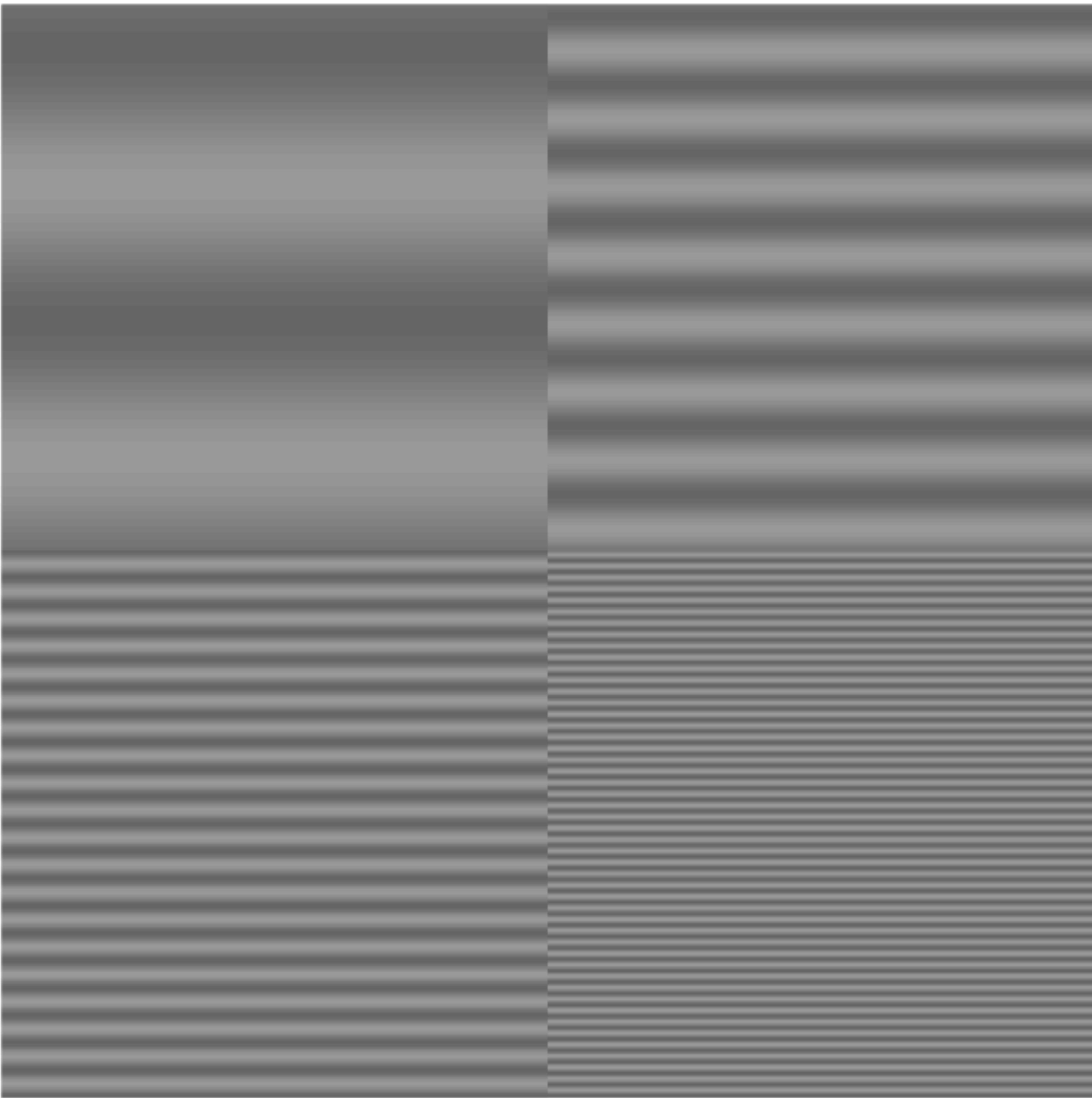
This research was partially supported by NSF Grant BNS-76-1839 to Norma Graham. We wish to thank Terry Schile for being such a helpful observer and research assistant. We are grateful to Jacob Nachmias and Bill Friedman for useful comments on an earlier draft of this manuscript. Requests for reprints should be sent to Norma Graham, Department of Psychology, Columbia University, New York 10027.

High-threshold models (e.g., Green & Weber, 1980) predict no effect of uncertainty. Uncertainty effects, however, have been reported for the spatial frequency of sinusoidal gratings (e.g., Davis & Graham, 1981; Graham, Robson, & Nachmias, 1978) and for spatial position of aperiodic visual targets (e.g., Cohn & Lasley, 1974; Pelli, 1981; Posner, 1978; Posner, Snyder, & Davidson, 1980).

The failure of the Quick pooling model to predict uncertainty effects seemed unimportant when the interpretations of experimental results depended on differences that were substantially larger than the uncertainty effects. Now, however, as the field has become more refined, the interpretation of experimental results is affected by uncertainty effects. (See, for example, the difference between the results in Graham & Nachmias, 1971, and those in Graham, Robson, & Nachmias, 1978.) Gaining a better understanding of these uncertainty effects, therefore, is critical for further development of these models of pattern vision. This study addresses several issues in the hope of contributing to such an understanding.

(1) Although the Quick pooling model does not predict uncertainty effects, other models assuming multiple mechanisms do (Ball & Sekuler, 1980; Creelman, 1960; Green & Swets, 1966; Green & Weber, 1980). These models are commonly called single-band and multiple-band models and are described further in the results section.

To determine whether single-band or multiple-band models (or perhaps neither) could explain the effects of uncertainty about spatial frequency, the detectability of several widely separated spatial frequencies was measured under conditions of both uncertainty and certainty using a temporal two-alternative



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J. Physiol. (1971), **219**, pp. 355–365
With 5 text-figures
Printed in Great Britain

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THE DETECTION OF GRATINGS IN NARROW-BAND VISUAL NOISE*

By BARBARA E. CARTER AND G. BRUCE HENNING†

From the Defence Research Establishment Toronto,
Downsview, Canada

(Received 24 May 1971)

SUMMARY

1. The detectability of sinusoidal gratings comprised of either one or many cycles was measured in veiling luminances the spatial frequencies of which were either narrow- or broad-band.

2. In narrow-band noise, the single-cycle grating was detected with approximately 0·6 log units less contrast than the many-cycle grating. On the other hand when both broad-band and narrow-band noise were present, there was no measurable difference in the detectability of the two types of grating.

3. The results are interpreted as supporting the hypothesis of Campbell & Robson (1968) that spatially varying luminance patterns are processed by mechanisms selectively sensitive to limited ranges of spatial frequencies.

INTRODUCTION

Campbell & Robson (1968), Blakemore & Campbell (1969) and Sachs, Nachmias & Robson (1971) have suggested that the behaviour of the eye in detecting or discriminating among spatial patterns can be described as that of a series of broadly tuned filters sensitive to approximately an octave band of spatial frequencies. The similarity between Helmholtz's theory of frequency representation in the auditory system and the Campbell & Robson model of visual spatial frequency analysis leads readily to the consideration of visual analogues of the many auditory experiments bearing on the frequency selectivity of the ear (Campbell, Nachmias & Jukes, 1970; Graham & Nachmias, 1971; Kulikowski, 1969). The experiment reported here is analogous to some auditory experiments of Wightman & Leshowitz (1970) and Leshowitz & Wightman (1971), and the results, readily predicted from Campbell & Robson's hypothesis, support the suggestion that in representing visual spatial frequencies the behaviour

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3. The results are interpreted as supporting the hypothesis of Campbell & Robson (1968) that spatially varying luminance patterns are processed by mechanisms selectively sensitive to limited ranges of spatial frequencies.

Three key findings

Detectability (i.e. threshold measurements) of simple gratings (sine-, square-, sawtooth gratings) can be predicted from the knowledge of the CSF and the Fourier spectrum of the gratings.

Discriminability (i.e. supra-threshold measurements) of simple gratings (sine-, square-, sawtooth gratings) can be predicted from the knowledge of the CSF and the Fourier spectrum of the gratings.

Adaptation to gratings of a certain frequency only affects the perception of gratings of similar frequency.

Together this suggests—is consistent with—that there exist “channels” in the visual system tuned to narrow ranges of spatial frequency, and that the CSF is the sum of many such channels.

... in the words of Campbell & Robson, 1968:

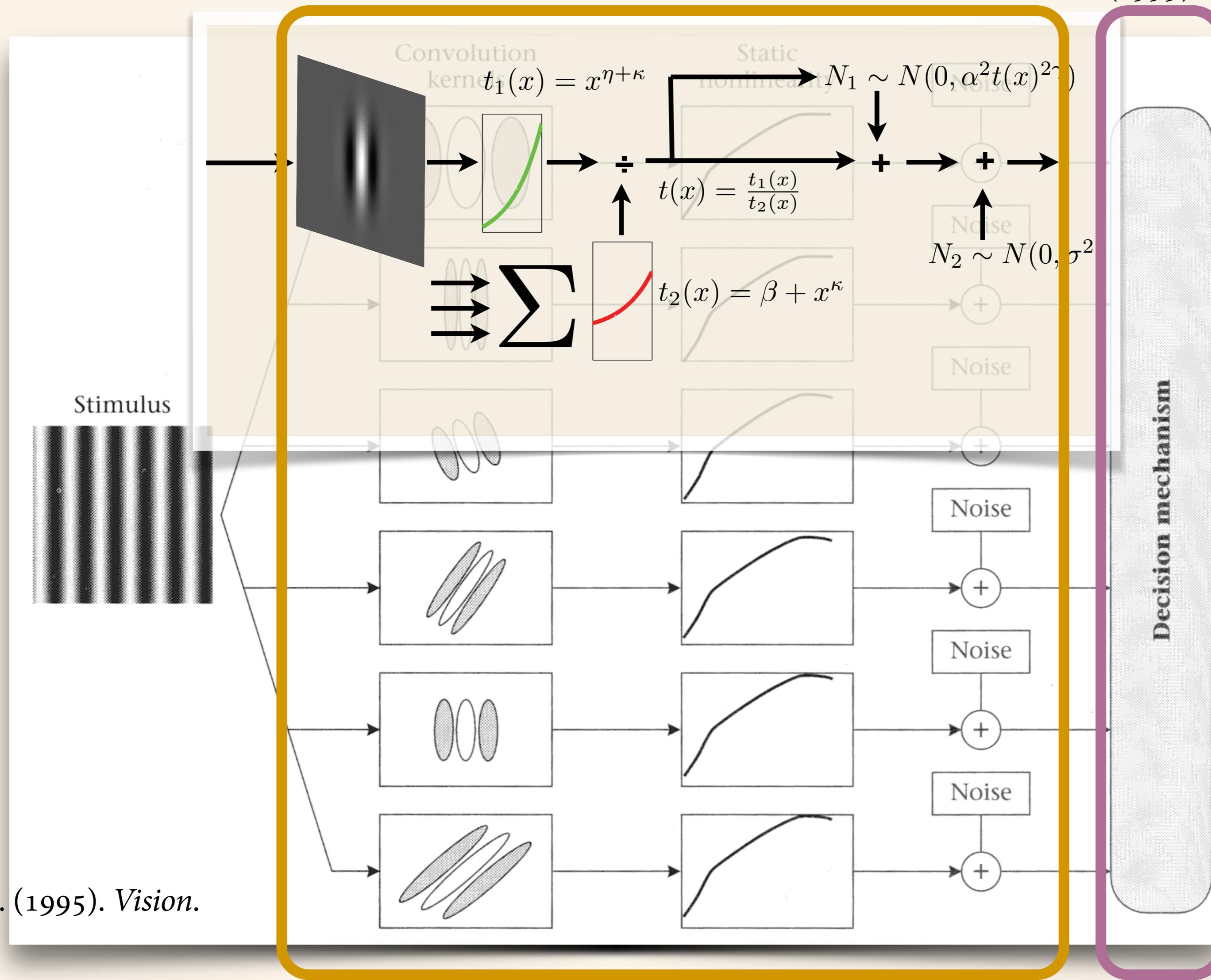
SUMMARY

1. The contrast thresholds of a variety of grating patterns have been measured over a wide range of spatial frequencies.
2. Contrast thresholds for the detection of gratings whose luminance profiles are sine, square, rectangular or saw-tooth waves can be simply related using Fourier theory.
3. Over a wide range of spatial frequencies the contrast threshold of a grating is determined only by the amplitude of the fundamental Fourier component of its wave form.
4. Gratings of complex wave form cannot be distinguished from sine-wave gratings until their contrast has been raised to a level at which the higher harmonic components reach their independent threshold.
5. These findings can be explained by the existence within the nervous system of linearly operating independent mechanisms selectively sensitive to limited ranges of spatial frequencies.

Standard multi-channel early spatial vision model

adapted from:

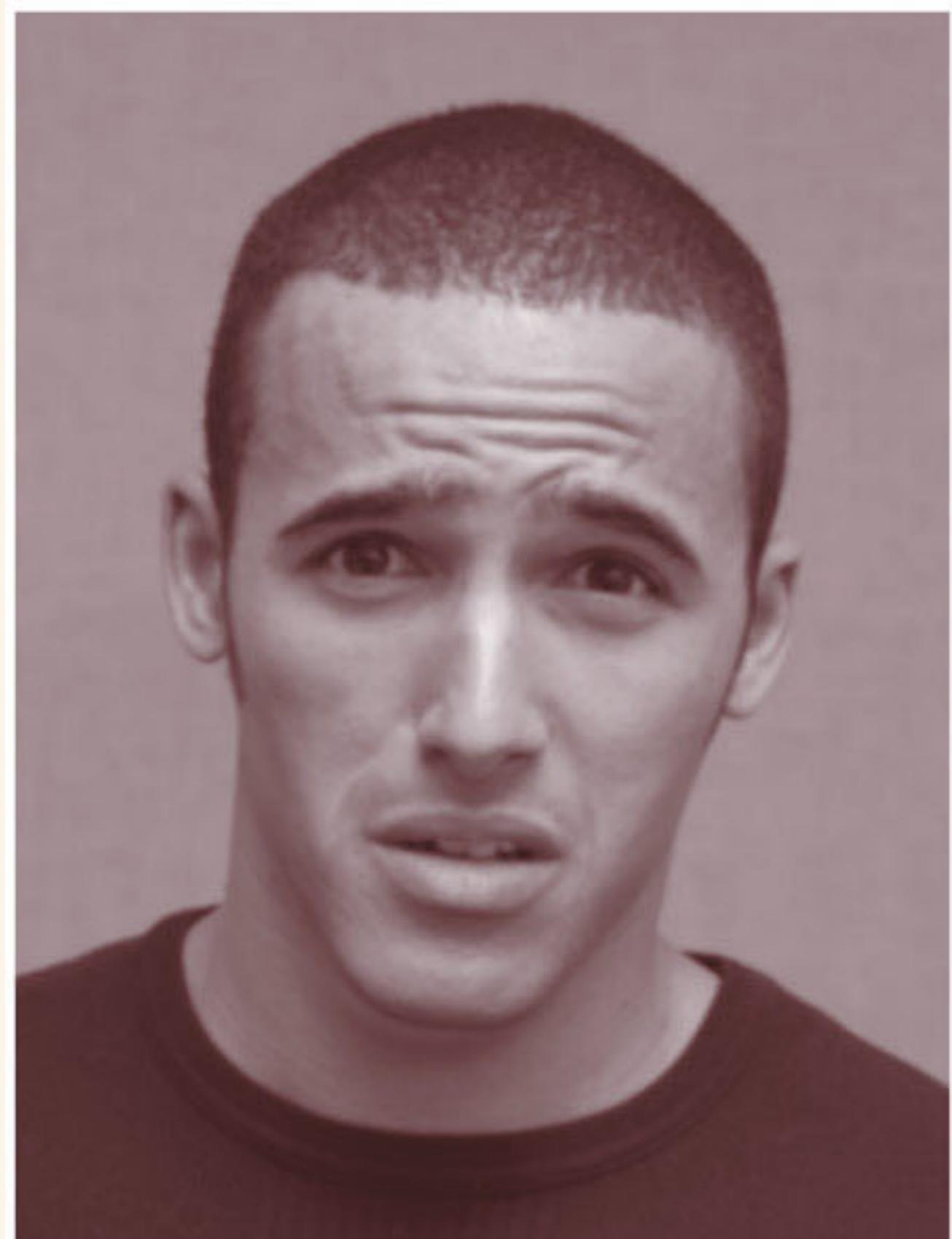
WICHMANN, F. A. (1999). *DPhil Thesis*, Oxford



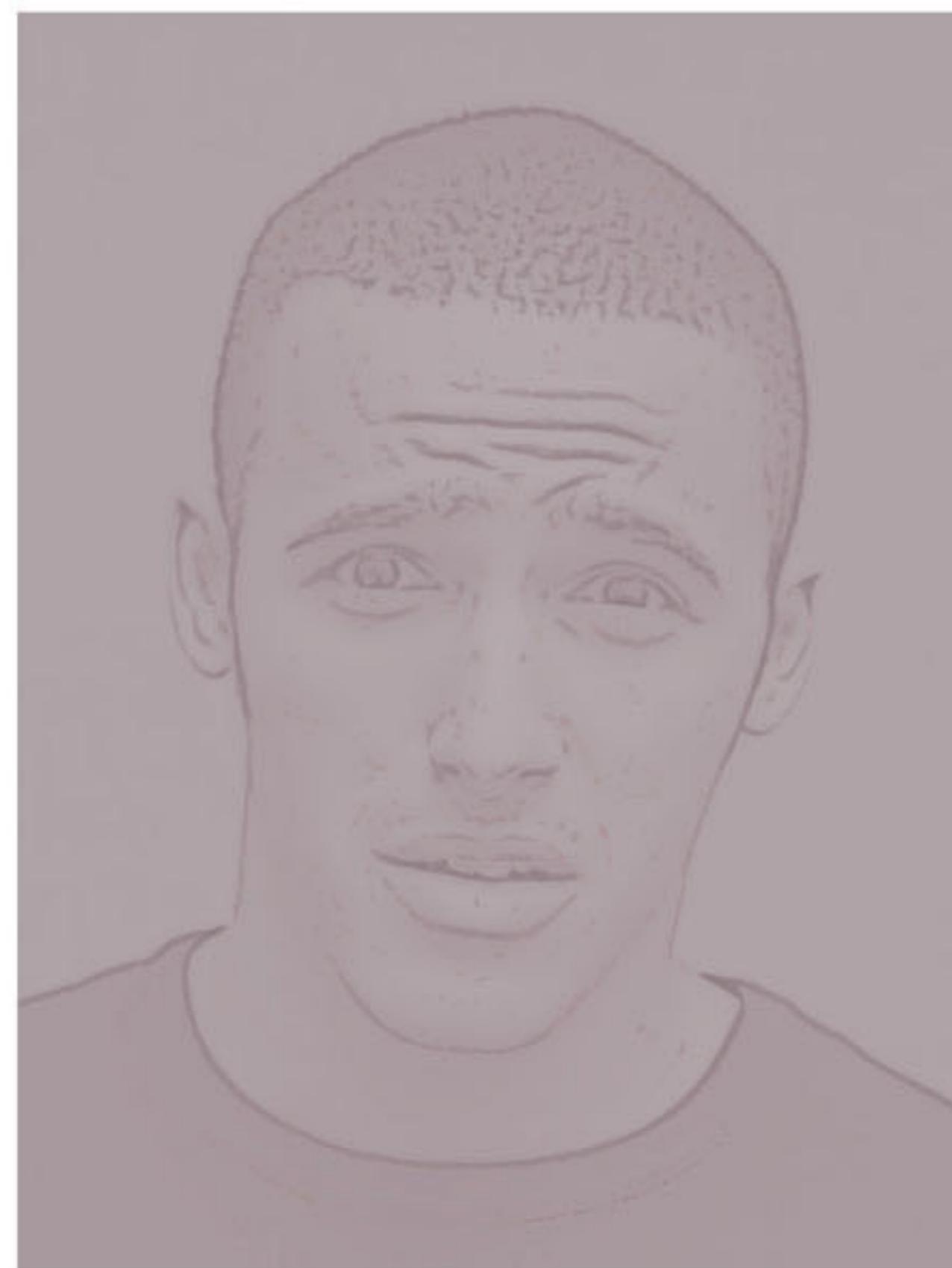
Encoding Stage

Decoding Stage

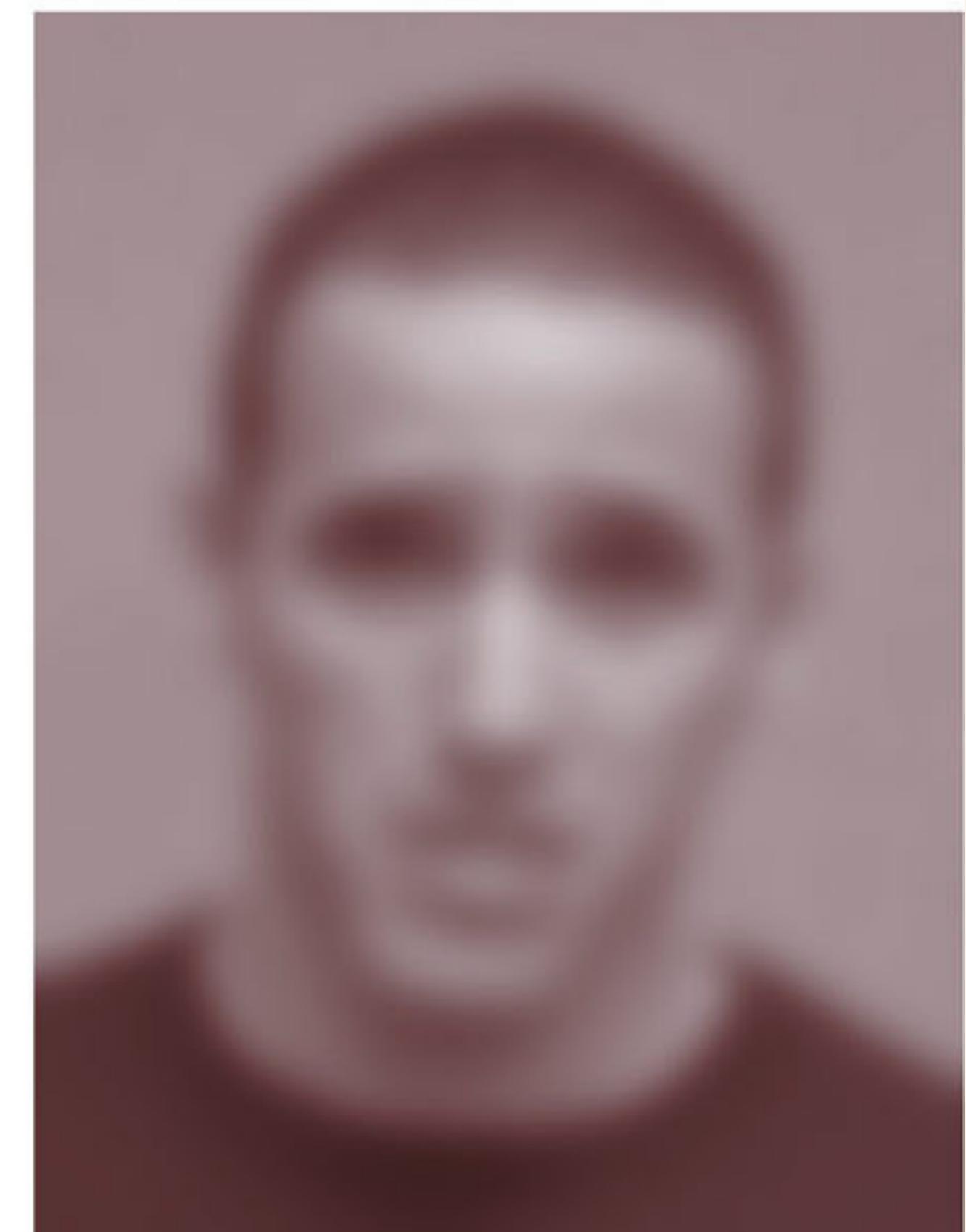
(a)



(b)



(c)



SENSATION & PERCEPTION 4e, Figure 3.34

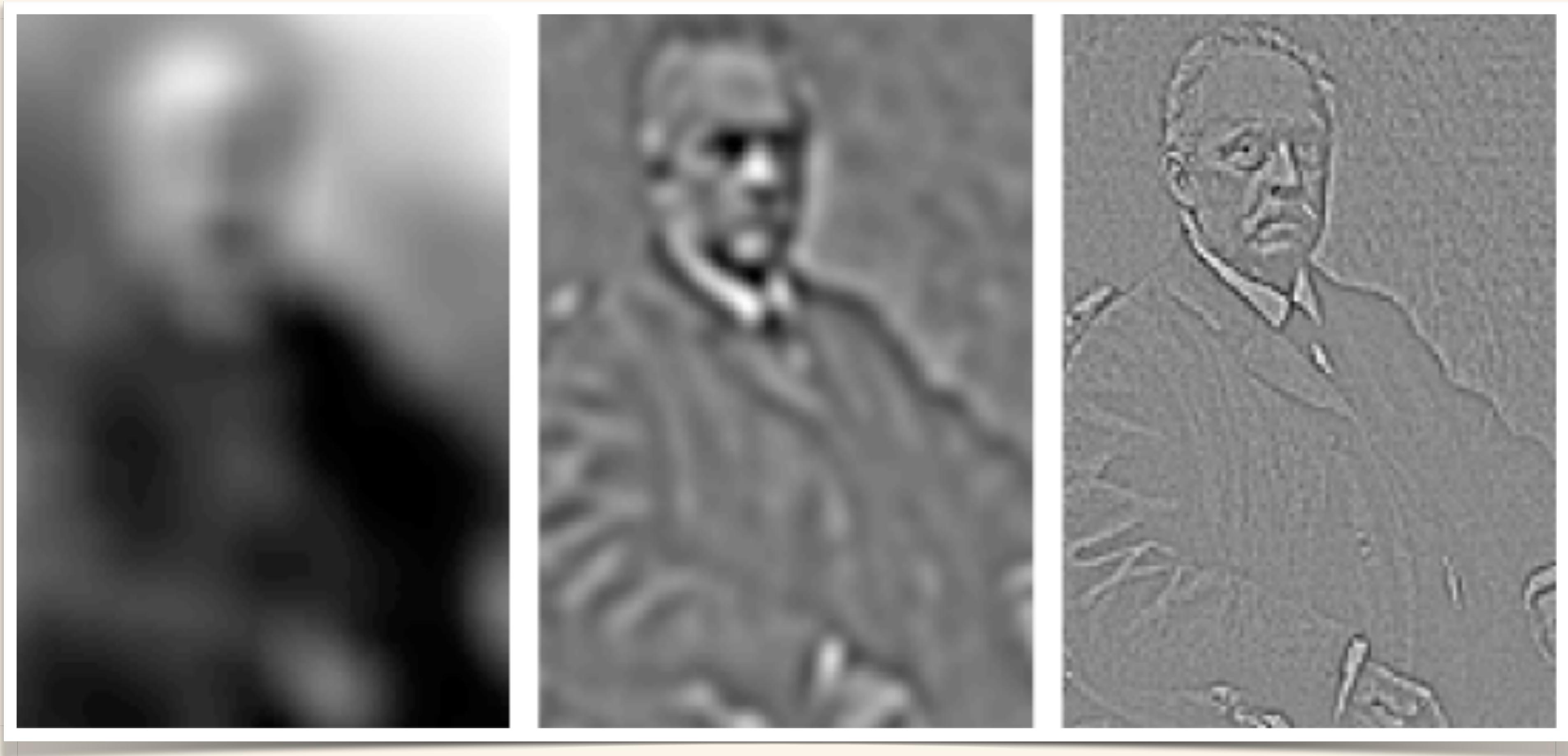
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Early Spatial Vision—Textbook Style



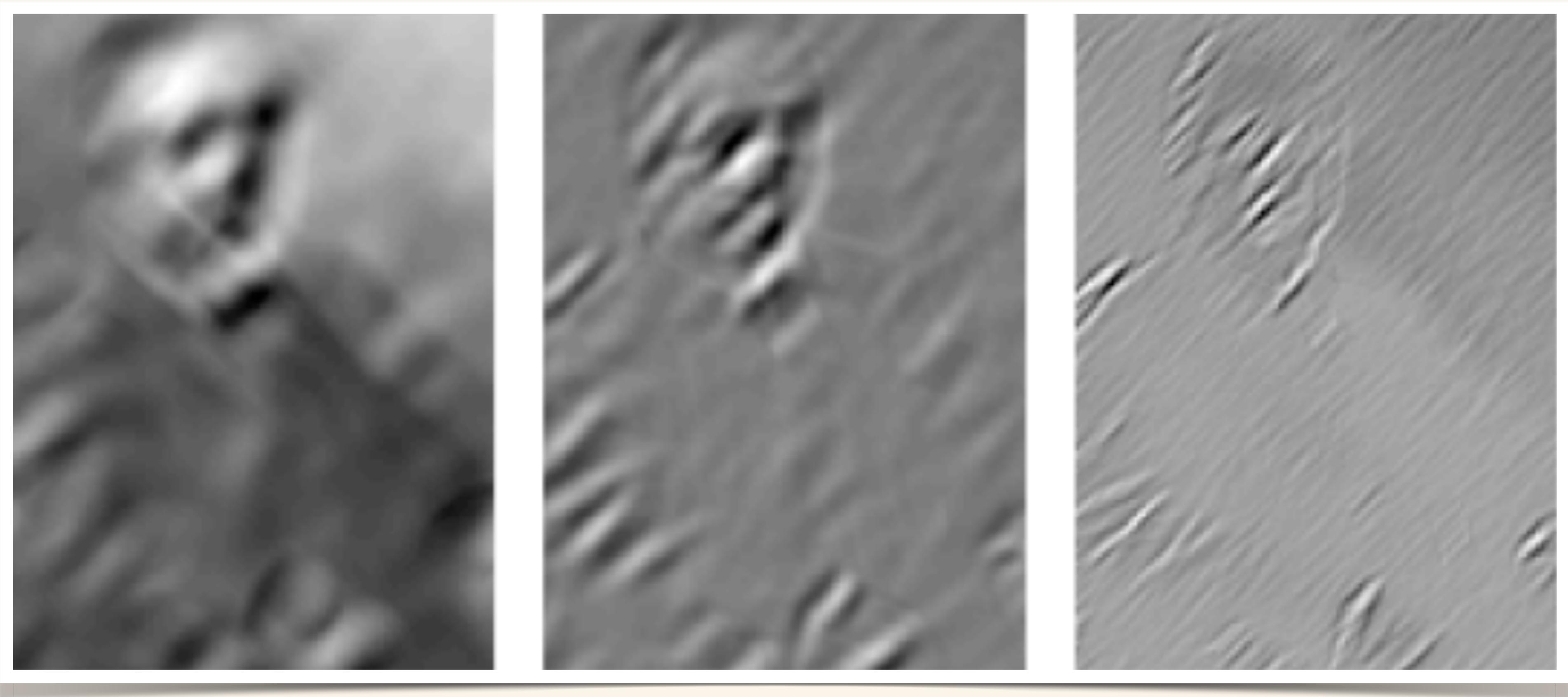
Hermann von Helmholtz

Early Spatial Vision—Textbook-Style



Helmholtz filtered with circularly-symmetric bandpass filters. Loosely corresponding to neural images at the level of retinal ganglion and LGN cells.

Early Spatial Vision—Textbook-Style



Helmholtz filtered with oriented bandpass filters (45° example shown). Loosely corresponding to neural images at the level of V1 simple cells.

Detection, summation and adaptation experiments are consistent with ...

... the early stages of the visual system behaving like linear, independent filters of limited bandwidth.

In the words of Campbell & Robson (1968):
“These findings can be explained by the existence within the nervous system of linearly operating independent mechanisms selectively sensitive to limited ranges of spatial frequency.”
(p. 551)

Striking similarity between Helmholtz’s theory of frequency representation in the auditory system and Campbell & Robson’s model of visual spatial frequency analysis.

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

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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.
2. Contrast thresholds for the detection of gratings whose luminance profiles are sine, square, rectangular or saw-tooth waves can be simply related using Fourier theory.
3. Over a wide range of spatial frequencies the contrast threshold of a grating is determined only by the amplitude of the fundamental Fourier component of its wave form.
4. Gratings of complex wave form cannot be distinguished from sine-wave gratings until their contrast has been raised to a level at which the higher harmonic components reach their independent threshold.
5. These findings can be explained by the existence within the nervous system of linearly operating independent mechanisms selectively sensitive to limited ranges of spatial frequencies.

INTRODUCTION

Our ability to perceive the details of a visual scene is determined by the relative size and contrast of the detail present. This is clearly demonstrated when the scene is an extended grating pattern whose luminance perpendicular to the bars is modulated sinusoidally about a fixed mean level (sine-wave grating: Fig. 1). In this case the threshold contrast* necessary for perception of the bars is found to be a function of the spatial frequency of the grating. The reciprocal of the threshold contrast is the ‘contrast sensitivity’ and the variation of the sensitivity over a range of spatial frequencies is described by the ‘contrast-sensitivity function’.

The first measurement of the contrast-sensitivity function of the human visual system was reported by Schade in 1956. Schade interpreted his

* In this work we follow Michelson (1927), who defined the contrast of a grating as the maximum luminance minus the minimum luminance divided by twice the mean luminance, as illustrated in Fig. 1.

The Plenoptic Function and the Elements of Early Vision

Edward H. Adelson and
James R. Bergen

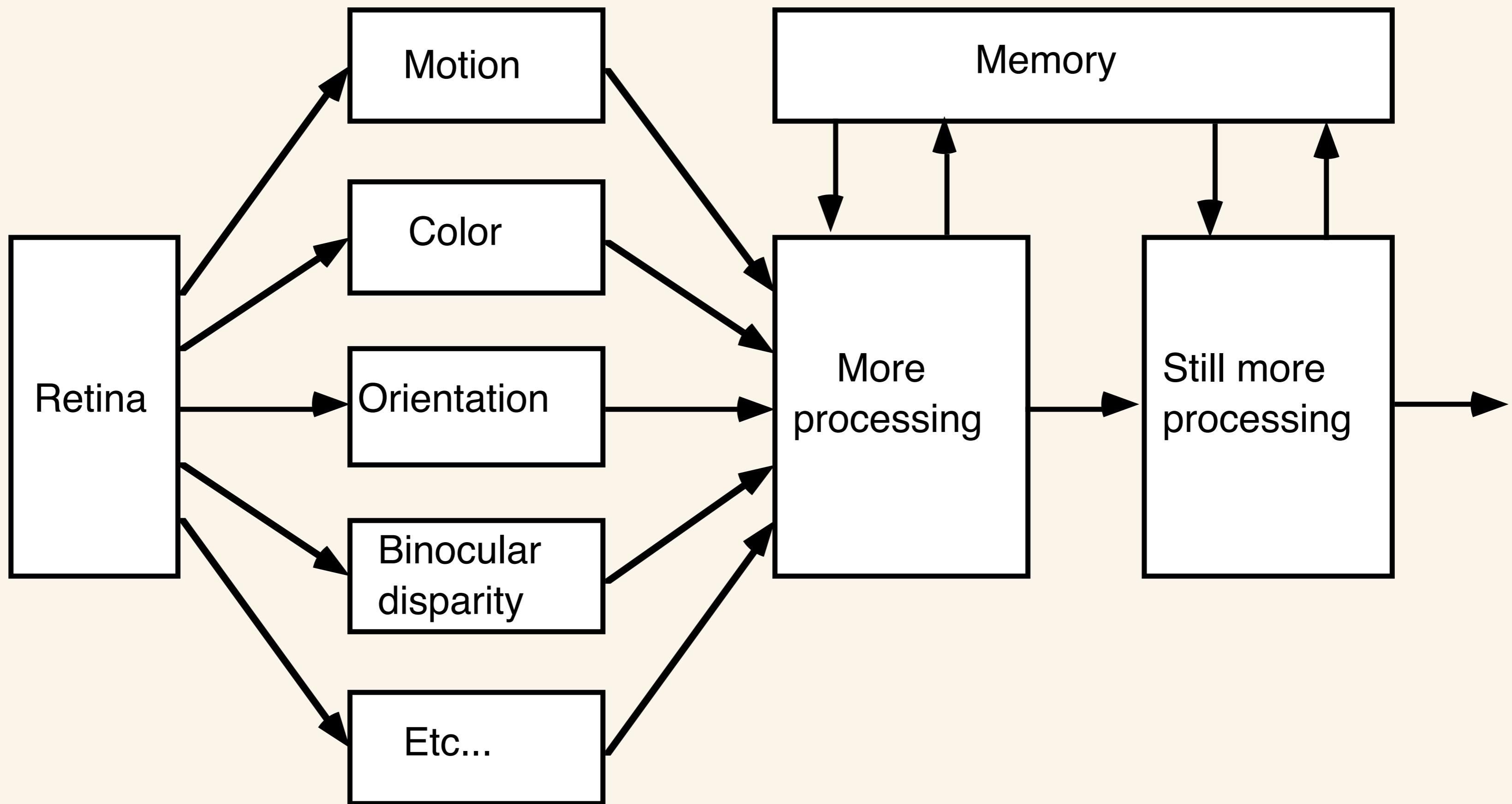
What are the elements of early vision? This question might be taken to mean, What are the fundamental atoms of vision?—and might be variously answered in terms of such candidate structures as edges, peaks, corners, and so on. In this chapter we adopt a rather different point of view and ask the question, What are the fundamental *substances* of vision? This distinction is important because we wish to focus on the first steps in extraction of visual information. At this level it is premature to talk about discrete objects, even such simple ones as edges and corners.

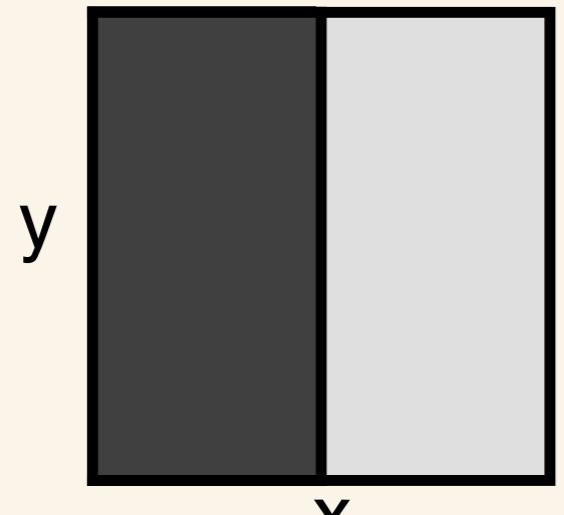
There is general agreement that early vision involves measurements of a number of basic image properties including orientation, color, motion, and so on. Figure 1.1 shows a caricature (in the style of Neisser, 1976), of the sort of architecture that has become quite popular as a model for both human and machine vision. The first stage of processing involves a set of parallel pathways, each devoted to one particular-visual property. We propose that the measurements of these basic properties be considered as the elements of early vision. We think of early

Retinal
processing

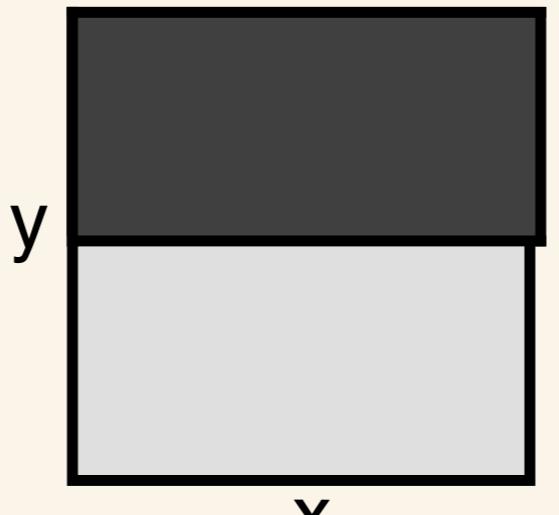
Early
vision

Higher-level
vision

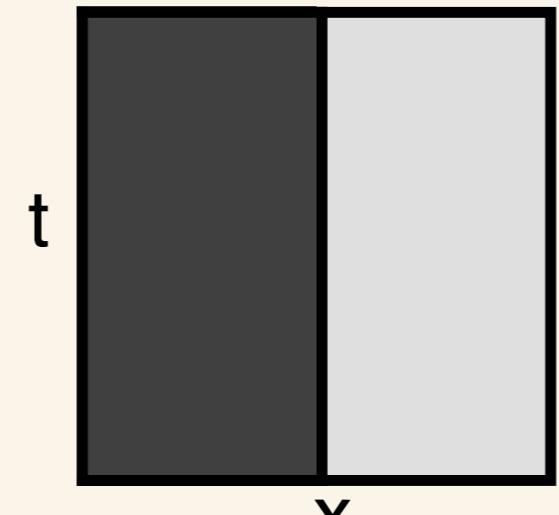




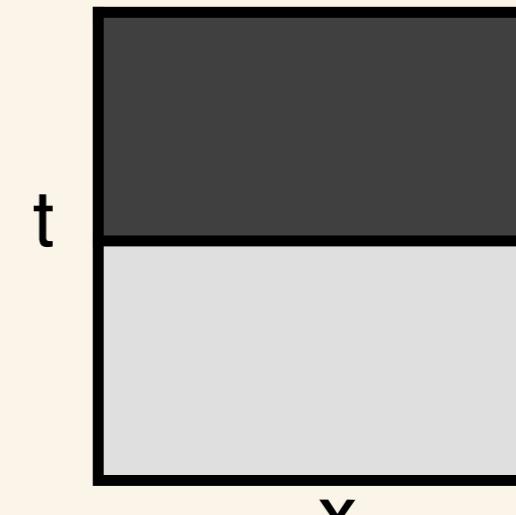
(a)



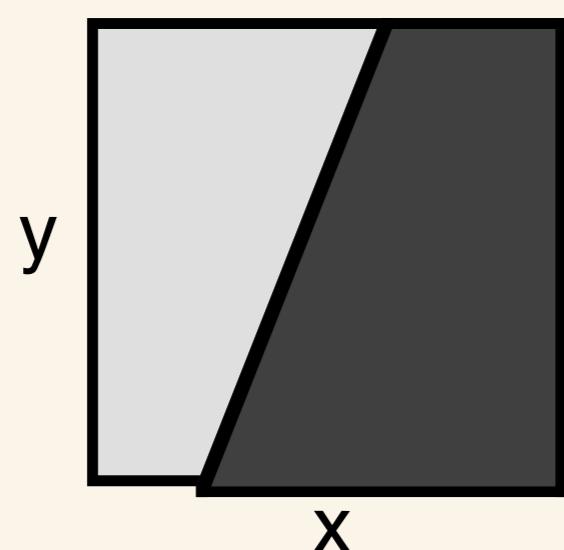
(b)



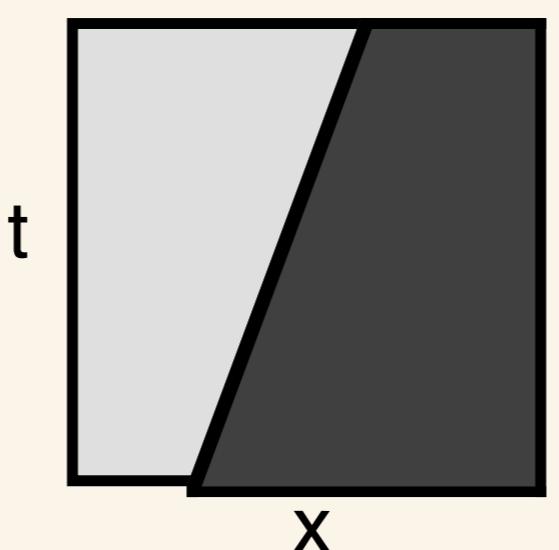
(c)



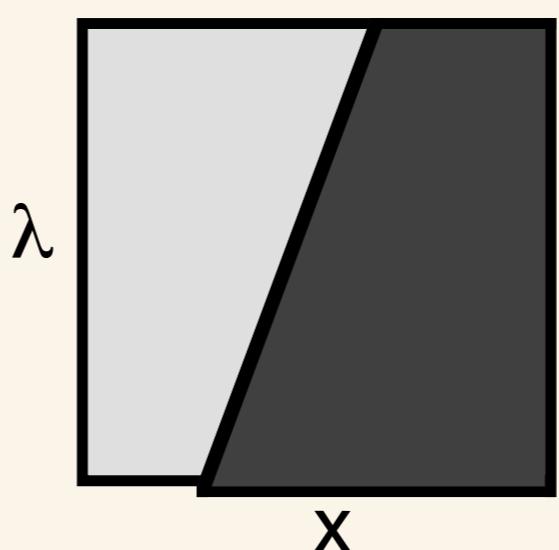
(d)



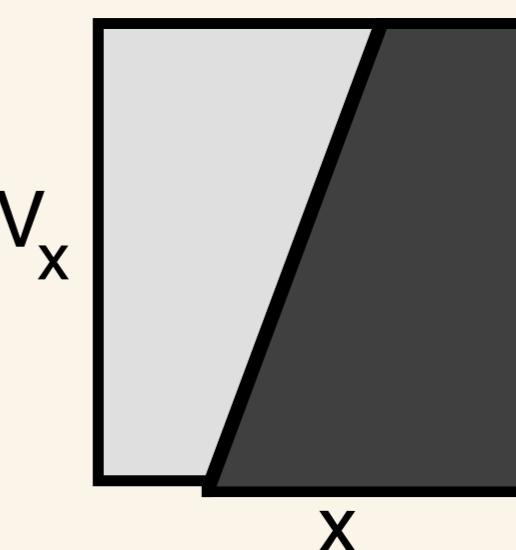
(e)



(f)



(g)



(h)

Fig. 1.4

Some edgelike structures that might be found along particular planes within the plenoptic function (note the venous axes, as labeled on each figure): (a) a vertical edge; (b) a horizontal edge, (c) a stationary edge; (d) a full-field brightening; (e) a tilting edge; (f) a moving edge; (g) a color sweep; (h) an edge with horizontal binocular parallax.

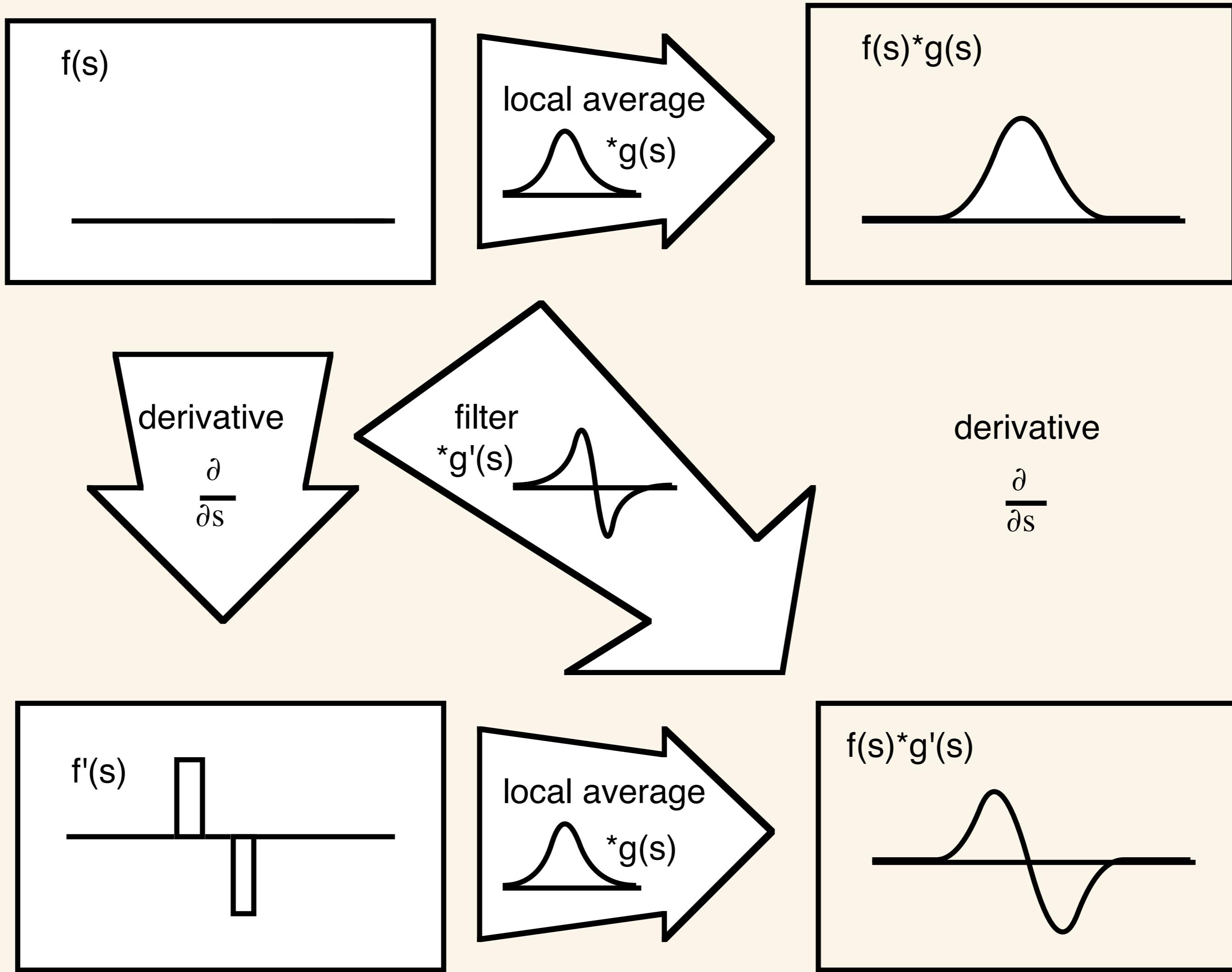


Fig. 7.7

The local average of a derivative is the same as the derivative of a local average.

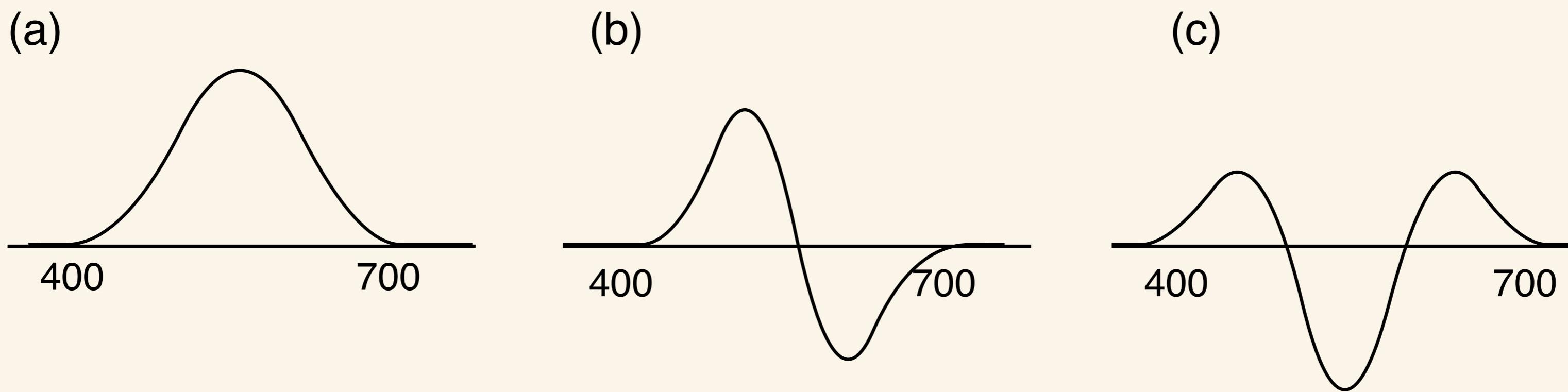


Fig. 1.11

The zeroth, first, and second derivatives of a Gaussian weighting function along the wavelength axis are similar to the luminance, blue-yellow, and red-green weighting functions found in the human visual system.

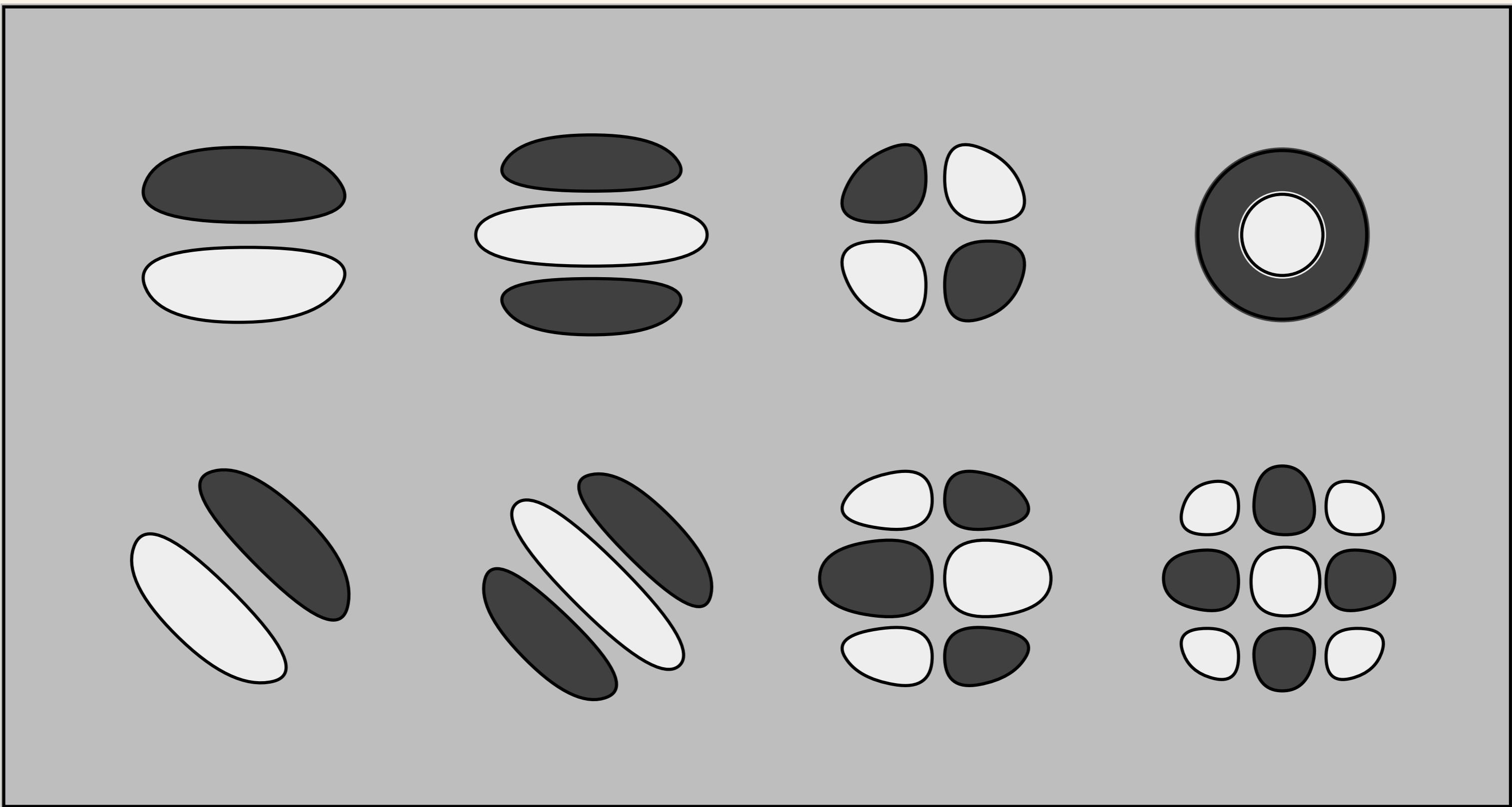


Fig.1.8

The low order derivative operators lead to a small number to two-dimensional receptive field types.

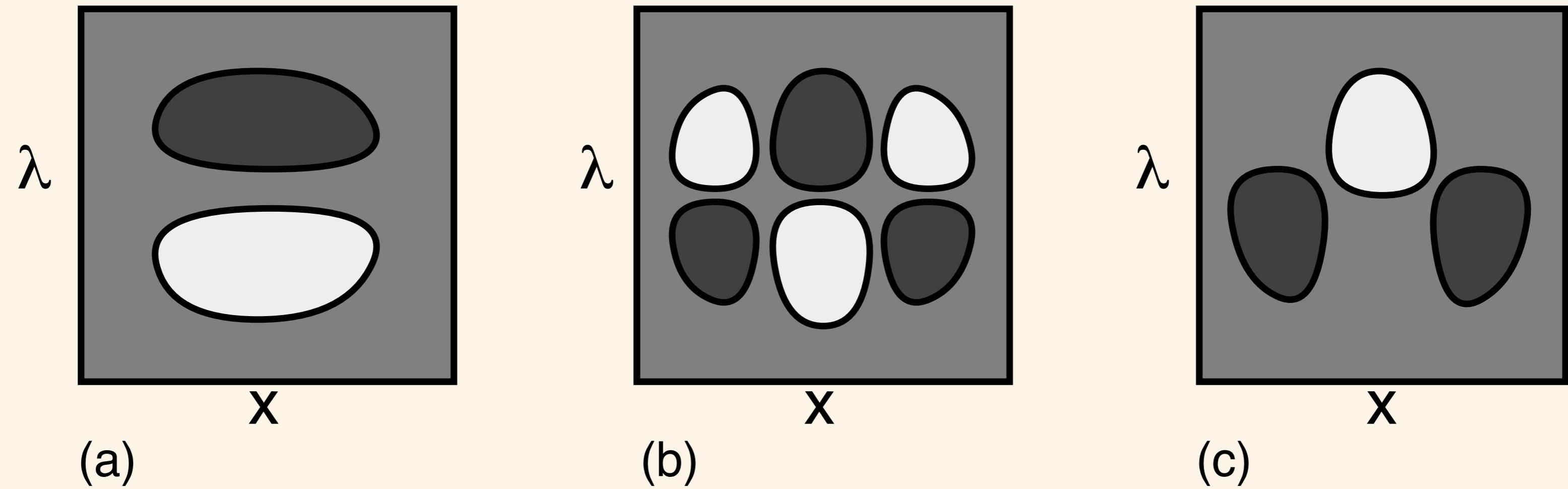


Fig.1.12

Spatiochromatic receptive fields may be used to characterize various color selective neurons: (a) an opponent color cell with no spatial structure; (b) a double opponent cell; (c) a single opponent cell. Note that this cell type does not correspond to a standard derivative type, although it may be constructed by taking sums of derivatives.

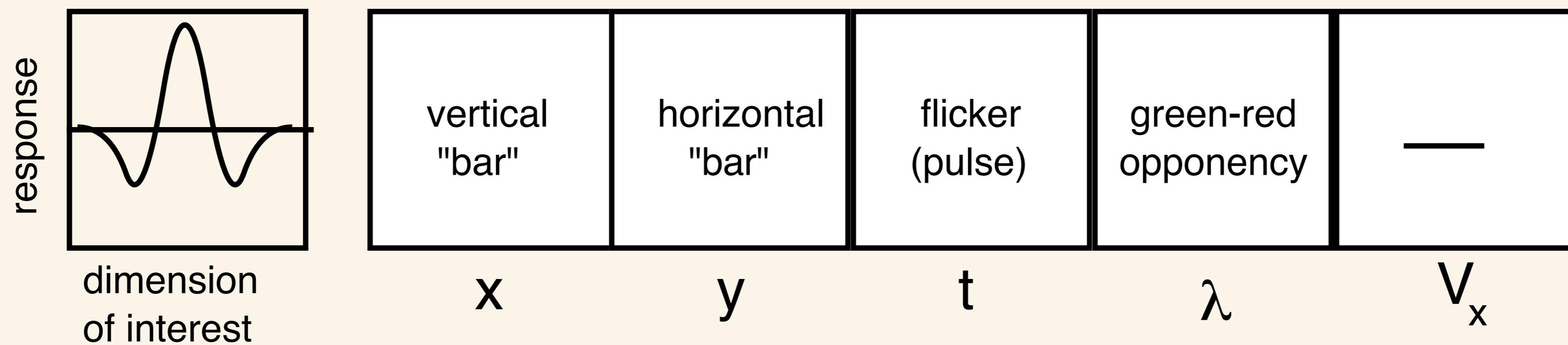
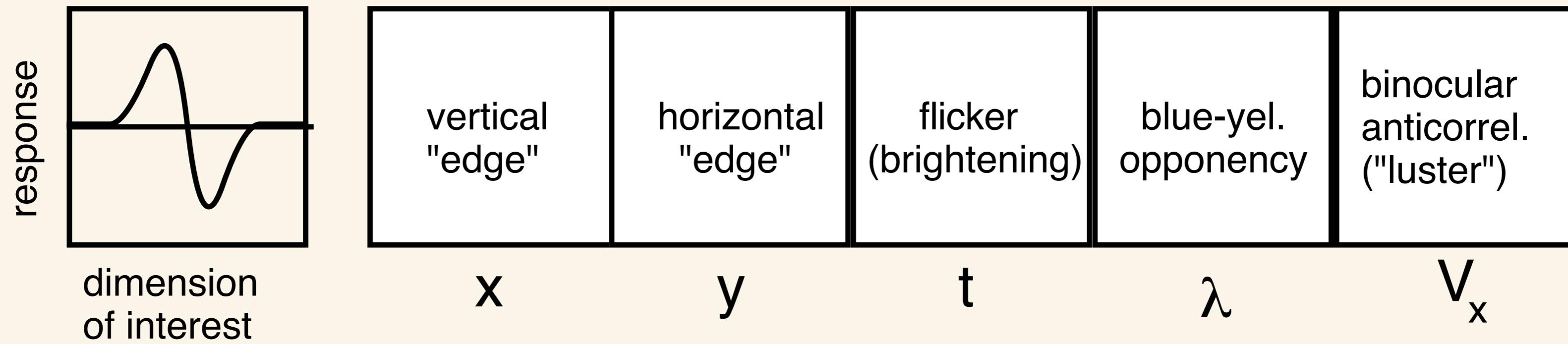
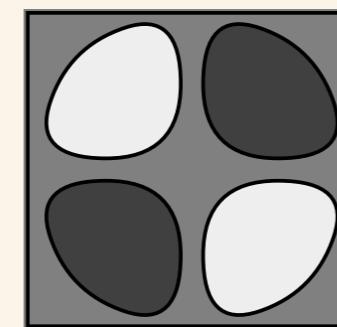
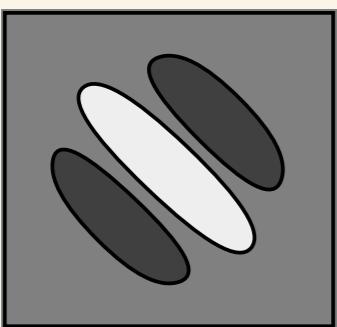


Fig.1.14

Derivatives along single dimensions lead to a number of basic visual measurements.



x	—				
y	diag. "bar" static achromatic no dispar	—			
t	vert. "bar" leftward achromatic no dispar	hor. "bar" downward achromatic no dispar	—		
λ	vertical static hue-sweep no dispar	horiz. static hue-sweep no dispar	full-field sequential hue-sweep no dispar	—	
V_x	vert. "bar" static achromatic hor. dispar	hor. "bar" static achromatic vert. dispar	full-field sequential achromatic eye-order	full-field static hue-shift luster	—

x y t λ V_x

Fig.1.15

The ten entries in the section of the periodic table corresponding to a tilted second derivative. The entries on the diagonal are meaningless, and the entries in the upper triangle are the same as those in the lower triangle by symmetry.

x	—				
y	criss-cross static achromatic no dispar	—			
t	vert."edge" reversing achromatic no dispar.	hor "edge" reversing achromatic no dispar.	—		
λ	vert."edge" static blue-yel. no dispar.	hor. "edge" static blue-yel. no dispar.	full-field reversing blue-yel. no dispar.	—	
V_x	vert."edge" static achromatic anticorr.	hor. "edge" static achromatic anticorr.	full-field reversing achromatic anticorr.	full-field static blue-yel. anticorr.	—

x y t λ V_x

Fig.1.16

The entries in the periodic table corresponding to separable first derivatives along both axes. There are ten elementary measurements of this type

Evidence for the Standard Early Spatial Vision Model

Detection and discrimination of simple (periodic) patterns can be predicted from the Fourier amplitude spectrum of the stimuli (CAMPBELL & ROBSON, 1968).

Detection of compound gratings is consistent with independent, narrowly-tuned elements (“channels”) and, perhaps, weak probability summation (GRAHAM & NACHMIAS, 1971).

Adaptation studies, too, are considered to be consistent with the narrowly-tuned, independent, multi-channel model (BLAKEMORE & CAMPBELL, 1969).

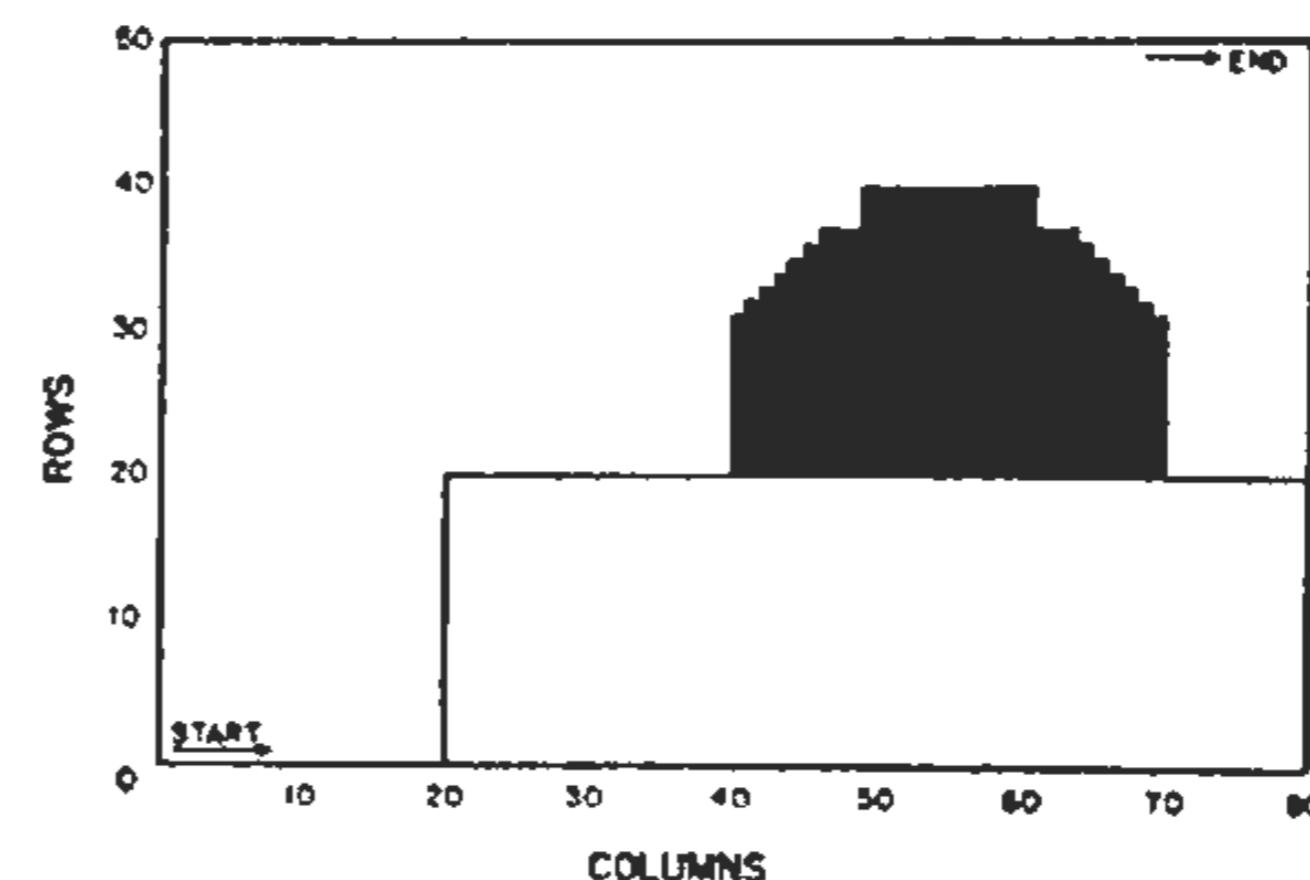
Almost “perfect” prediction of contrast discrimination behaviour given a within-channel non-linear transducer estimated from the data (FOLEY & LEGGE, 1981).

Worth thinking about the band-limited channels as local derivative operators (“measuring stuff”) in the spirit of ADELSON & BERGEN (1991): Mathematically exactly the same elements, but a different way of looking at, or representing, the same information.

In this paper I shall indicate some of the ways in which the concepts and techniques of information theory may clarify our understanding of visual perception. When we begin to consider perception as an information-handling process, it quickly becomes clear that much of the information received by any higher organism is *redundant*. Sensory events are highly interdependent in both space and time: if we know at a given moment the states of a limited number of receptors (i.e., whether they are firing or not firing), we can make better-than-chance inferences with respect to the prior and subsequent states of these receptors, and also with respect to the present, prior, and subsequent states of other receptors. The preced-

THE NATURE OF REDUNDANCY IN VISUAL STIMULATION: A DEMONSTRATION

Consider the very simple situation presented in Fig. 1. With a modicum of effort, the reader may be able to see this as an ink bottle on the corner of a desk. Let us suppose that the background is a uniformly white wall, that the desk is a uniform brown, and that the bottle is completely black. The visual stimulation from these objects is highly redundant in the sense that portions of the field are highly predictable from other portions. In order to demonstrate this fact and its perceptual significance, we may employ a variant of the "guessing game" technique with which Shannon (17) has studied the



Attneave (1954), p. 183

FIG. 1. Illustration of redundant visual stimulation

How complex or simple a structure is depends crucially upon the way we describe it. Most of the complex structures found in the world are enormously redundant, and we can use this redundancy to simplify their description. But to use it, to achieve the simplification, we must find the right representation.

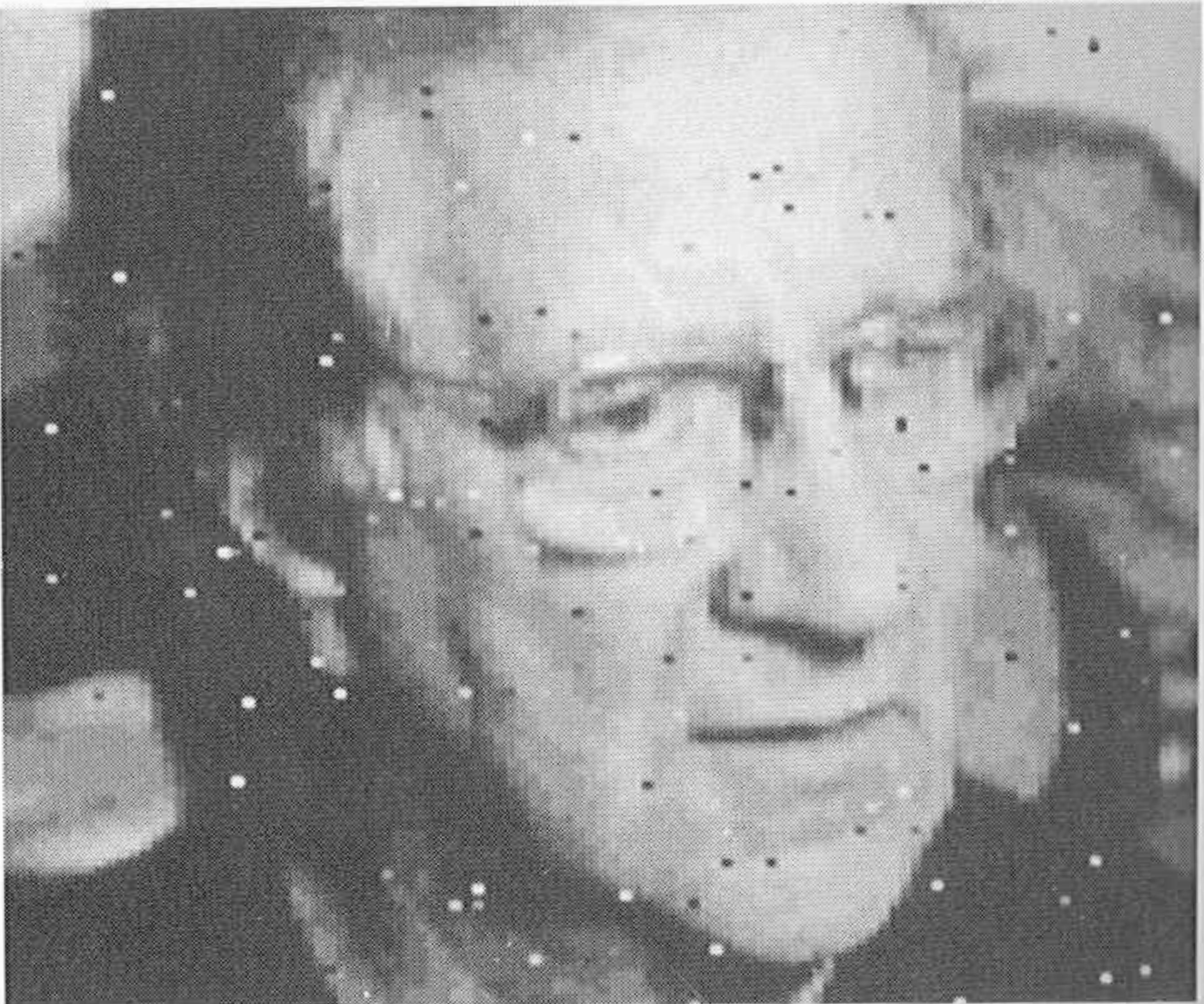
Herbert A. Simon, The Sciences of the Artificial, MIT Press, 1968

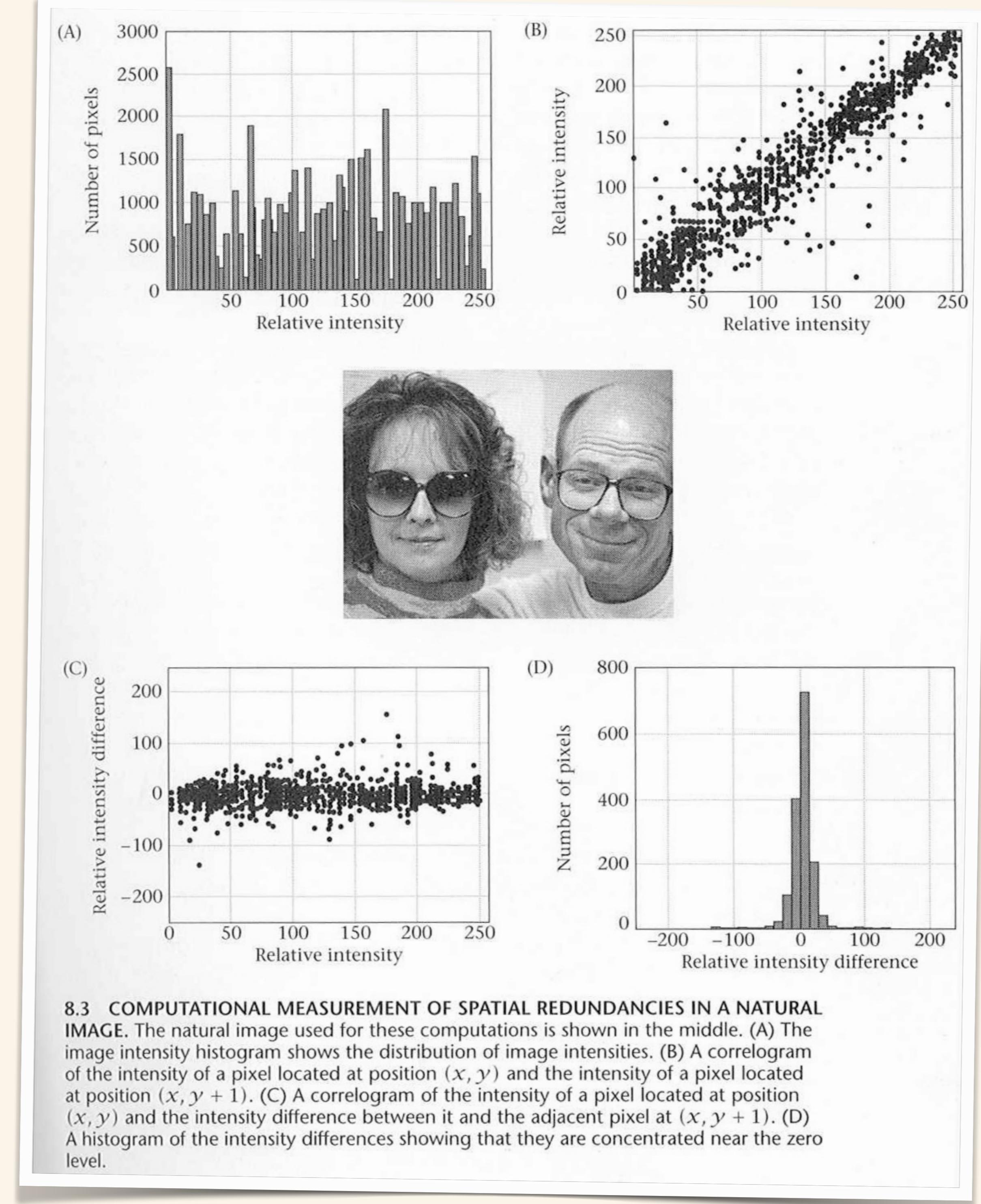
As ... pointed out, an efficient sensory system should match its analyzers to the nature of the signals it processes. If images of the natural environment were truly random, then a statistical match would not be possible. However, natural images are not random, and the redundant properties can be exploited to provide an efficient code.

D.J. Field (1987), p. 2393

8.2 EXPERIMENTAL MEASUREMENT OF SPATIAL REDUNDANCY IN AN IMAGE.

The image shows Professor Horace Barlow; random noise has been added to the picture. Subjects were asked to adjust the intensity of the noisy pixels to the level they thought must have been present in the original image. Subjects are very accurate at this task, using the information present in nearby pixels. This is an experimental demonstration that people can take advantage of the spatial redundancy in image data. Source: Kersten, 1987.





Relations between the statistics of natural images and the response properties of cortical cells

David J. Field

Physiological Laboratory, University of Cambridge, Cambridge CB2 3EG, UK

Received May 15, 1987; accepted August 14, 1987

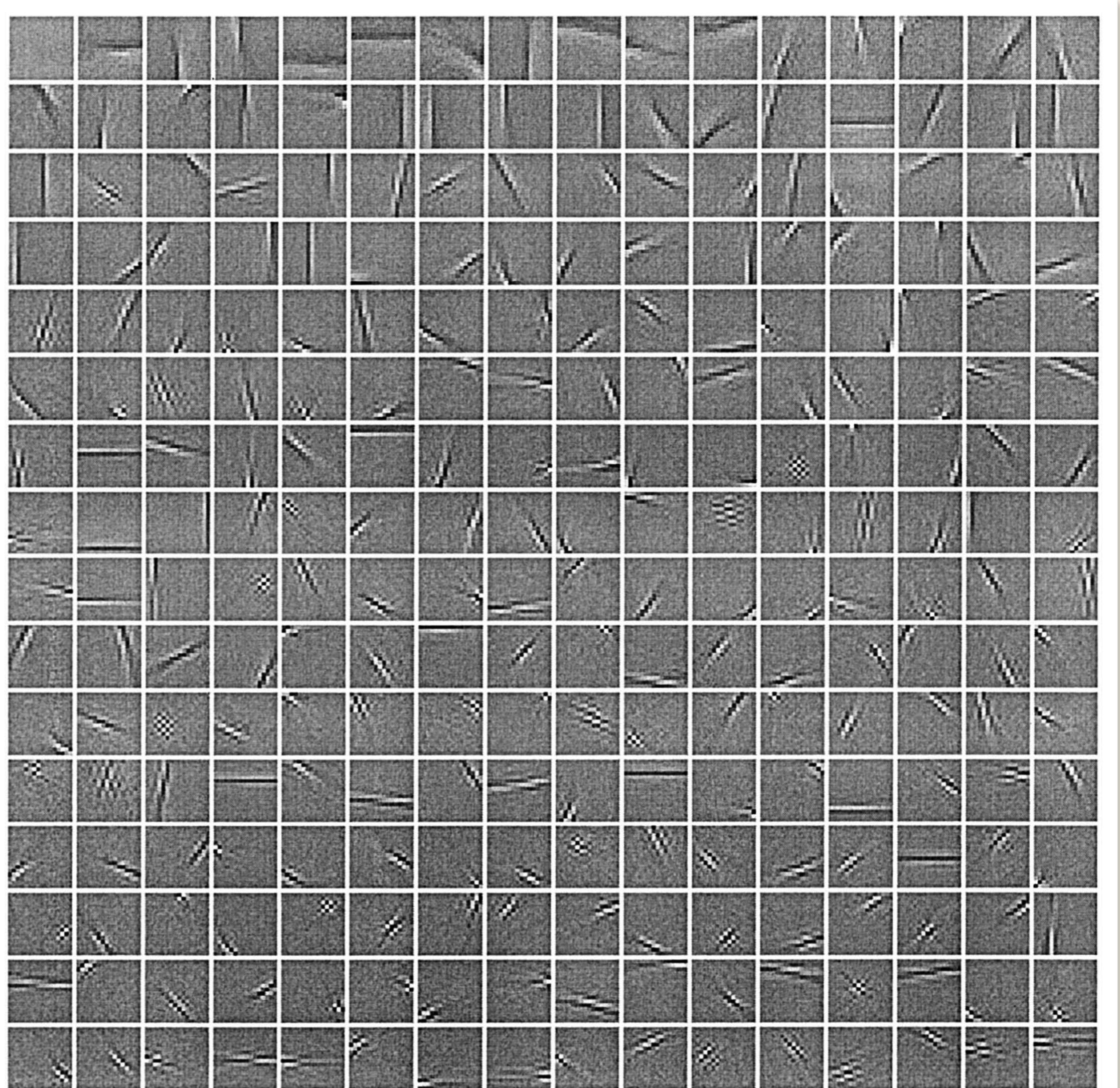
The relative efficiency of any particular image-coding scheme should be defined only in relation to the class of images that the code is likely to encounter. To understand the representation of images by the mammalian visual system, it might therefore be useful to consider the statistics of images from the natural environment (i.e., images with trees, rocks, bushes, etc.). In this study, various coding schemes are compared in relation to how they represent the information in such natural images. The coefficients of such codes are represented by arrays of mechanisms that respond to local regions of space, spatial frequency, and orientation (Gabor-like transforms). For many classes of image, such codes will not be an efficient means of representing information. However, the results obtained with six natural images suggest that the orientation and the spatial-frequency tuning of mammalian simple cells are well suited for coding the information in such images if the goal of the code is to convert higher-order redundancy (e.g., correlation between the intensities of neighboring pixels) into first-order redundancy (i.e., the response distribution of the coefficients). Such coding produces a relatively high signal-to-noise ratio and permits information to be transmitted with only a subset of the total number of cells. These results support Barlow's theory that the goal of natural vision is to represent the information in the natural environment with minimal redundancy.

Independent components of natural images

Independent features of natural images
(ICA analysis, Hyvärinen&Oja, 2000)

If the cells/convolution kernels/
frequency channels looked like the
independent components of the
stimuli they encode, their responses
are maximally independent:

1. redundancy reduction
2. sparseness (energy efficiency
when thinking about biological
systems)



from: Hyvärinen & Oja (2000)

Summary of Natural Image Statistics

Images (photos of the world) are highly redundant—that is, individual pixel intensities are highly predictable from neighbouring pixels, there exist strong statistical regularities.

Furthermore, the statistical regularities are such that the (most) independent basis functions for images look similar to visual cells in the early visual areas.

Spatial-frequency tuning of visual cells (“zero-mean bandpass-filter”) or the psychophysically measured “narrowly tuned” spatial-frequency channels—see Campbell & Robson (1968)—can be understood as redundancy reduction (normative role of the tuning).

SOME EXPERIMENTS BEARING ON THE HYPOTHESIS THAT THE VISUAL SYSTEM ANALYSES SPATIAL PATTERNS IN INDEPENDENT BANDS OF SPATIAL FREQUENCY¹

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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.

INTRODUCTION

Campbell and Robson (1968) have suggested that the visual system might act as if it were composed of many independent linear mechanisms, sometimes called "channels", each selectively sensitive to a limited range of spatial frequencies. They based their hypothesis on the finding that a grating with alternating black and white bars was detected at contrasts consistent with their observers' detecting only one of the spatial frequency components of which the grating was comprised. The particular component of the pattern to which the visual system was most sensitive depended on the contrast of the various components of the pattern and on the sensitivity of the visual system at the spatial frequency of each component. A great deal of evidence supporting Campbell and Robson's notion has accumulated; studies of the detectability of complex gratings (Graham and Nachmias, 1971; Sachs, Nachmias, and Robson, 1971), experiments showing that adaptation effects are confined to narrow bands of spatial frequency (Blakemore and Campbell, 1969), and simultaneous masking experiments (Carter and Henning, 1971; Stromeier and Julesz, 1973; Henning and Hertz, 1974; Sansbury, 1974) all provide results consistent with Campbell and Robson's hypothesis.

The experiments reported here show reciprocal masking between patterns that have the same periodicity although they occupy bands of spatial frequency that are at least two octaves apart. These experiments are not consistent with the hypothesis that the visual system analyses spatial patterns in independent channels each sensitive only to a range of spatial frequencies an octave above and below the most sensitive frequency of the channel.

The stimuli we used were a low-frequency sinusoidal grating and a complex grating having three components of high spatial frequency.

It is important to realize that a grating can be periodic, that is, it can repeat in some spatial interval, without having a component at the spatial frequency corresponding to its period. For example, one of our complex gratings contained components at about 8, 10 and 12 c/deg. The three-component grating looks like a 10 c/deg grating with a contrast that varies across the visual field. The contrast in fact varies sinusoidally and the entire pattern repeats twice every degree. Thus the pattern has a period that corresponds to the low spatial frequency of 2 c/deg, even though the lowest spatial frequency of its three components is 8 c/deg.²

The distinction between the period of a waveform and the frequency region of its components is important in auditory psychophysics. In vision, however, the periodicity of a grating has not often been experimentally separated from the frequency of the components of the grating. Our experiment with simple sinusoidal gratings, in which spatial frequency and the reciprocal of the period are necessarily the same, give results consistent with Campbell and Robson's hypothesis—there is little interaction between sinusoidal gratings that differ by more than a factor of two in spatial frequency; on the other hand, our experiments with complex gratings show large interactions between gratings that are much farther apart in frequency.

GENERAL PROCEDURE

Each of our experiments was a two-alternative forced-choice grating detection experiment. The signal grating was presented in one of two observation intervals each 1 sec in duration and separated by a 600-msec pause. The observers (the same two in all experiments)³ were required to indicate in a subsequent 750-msec answer interval whether the first or second observation interval had contained the signal. The observers were then informed which interval had in fact contained the signal, and a new trial was begun. All intervals were clearly marked for the observers by bursts of audible noise delivered through earphones.

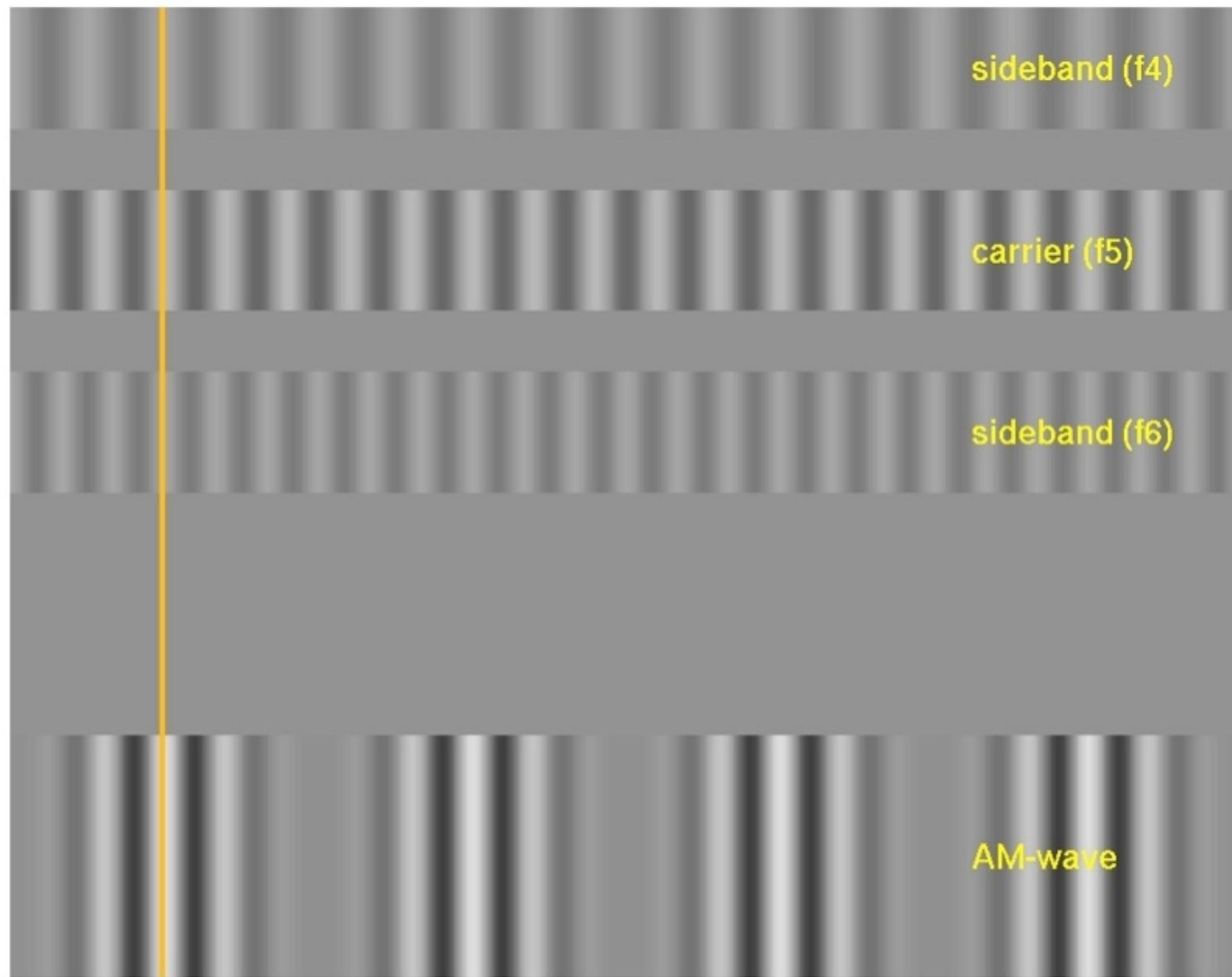
The probability that the signal was in the first interval was 0.5 on each trial and each trial lasted about 4 sec. After a block of 50 trials, the signal contrast (determined separately for each component of the stimulus as the ratio of the difference between the maximum and minimum luminance of the component to the sum of the maximum and minimum luminance of that component) was changed and a new block of 50 trials begun. In this way, we determined psychometric functions relating the percentage of correct responses to sig-

¹ This research was carried out while we were at the Applied Psychology Unit in Cambridge and one of us (GBH) was employed by the Canadian Defence and Civil Institute of Environmental Medicine.

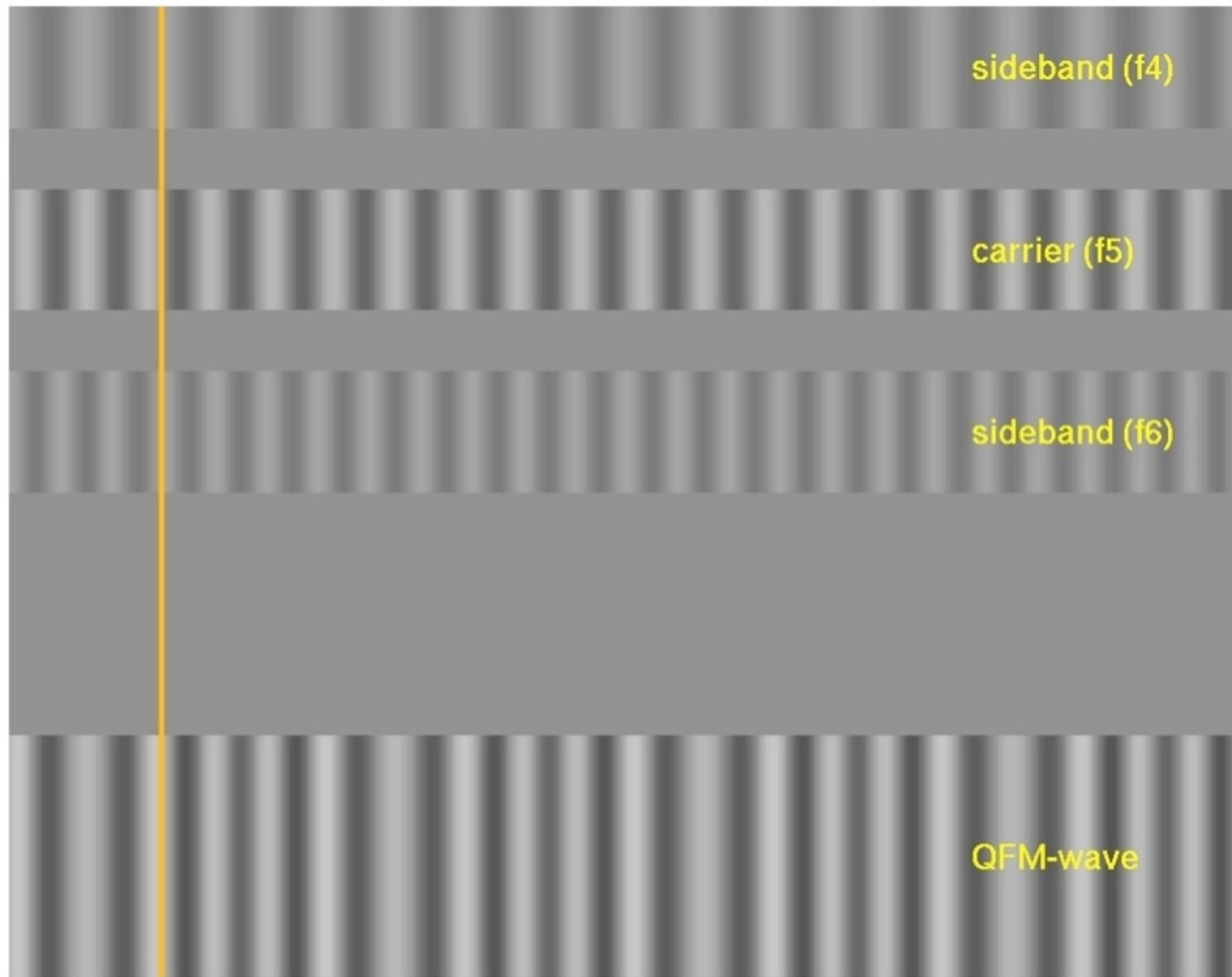
² The finite 6° extent of the gratings implies that all the components we describe as spectral lines have an effective bandwidth of at least 0.17 c/deg. We shall ignore this effect throughout.

³ Two of the authors are the Observers (*Os*).

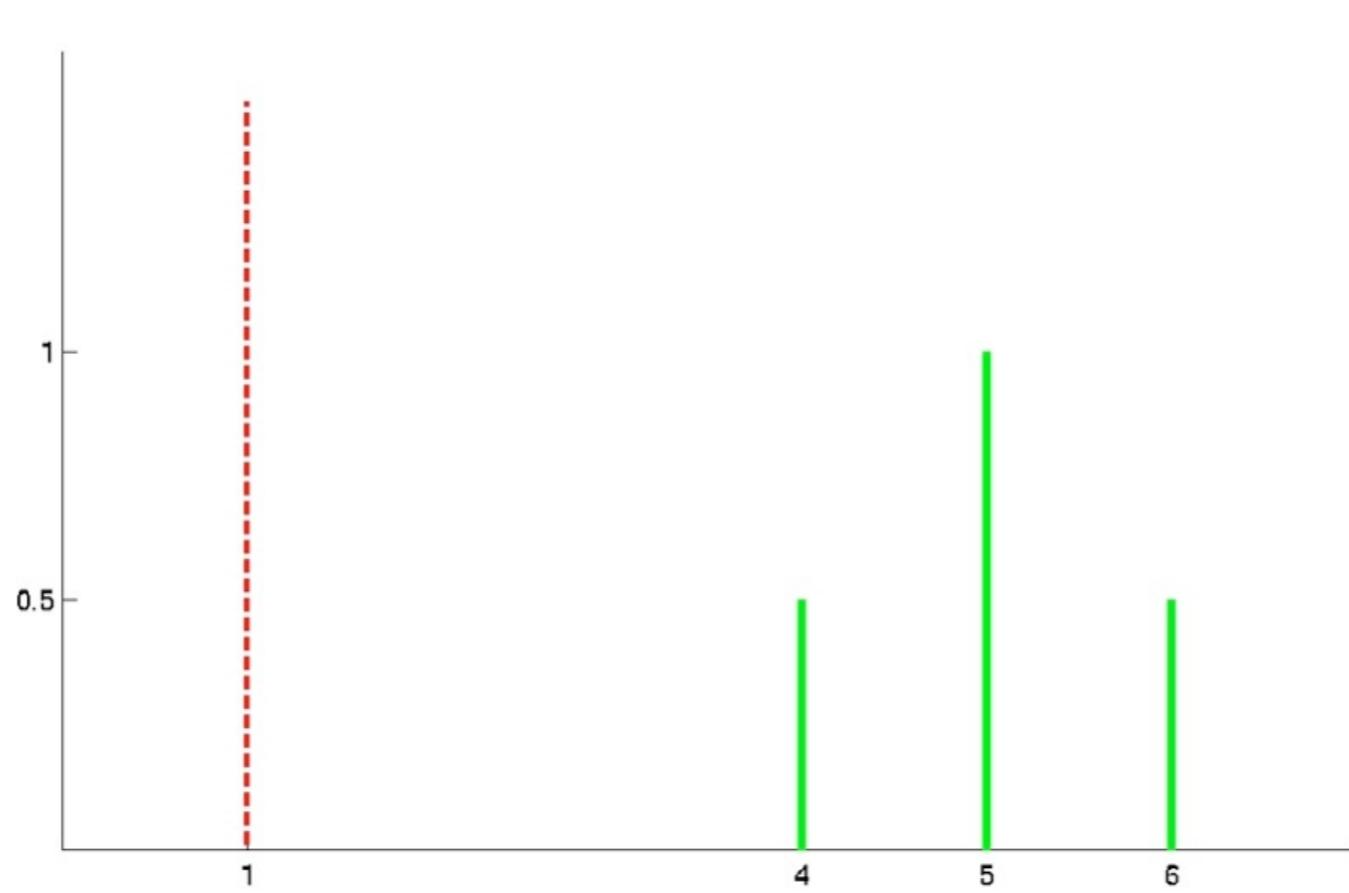
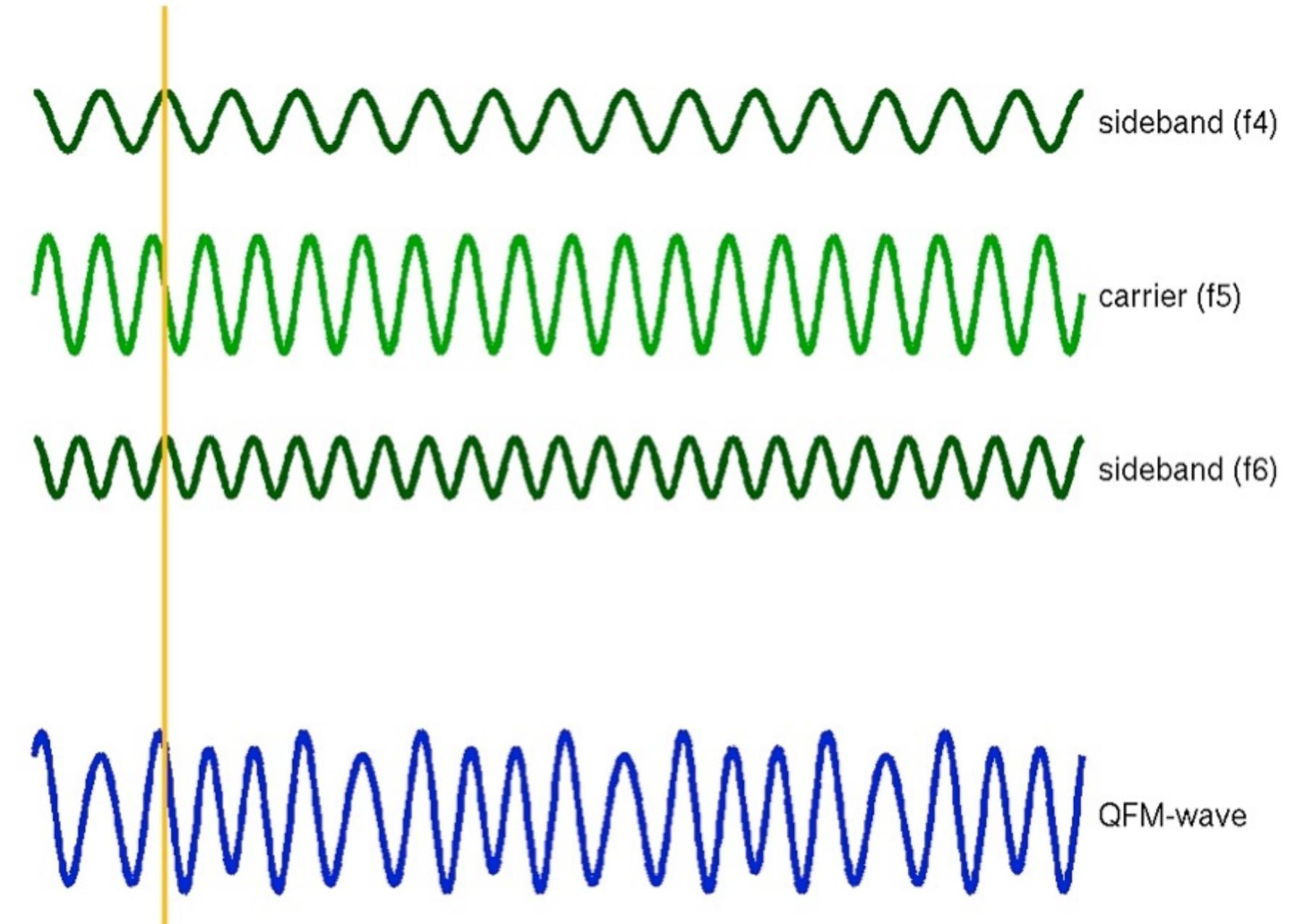
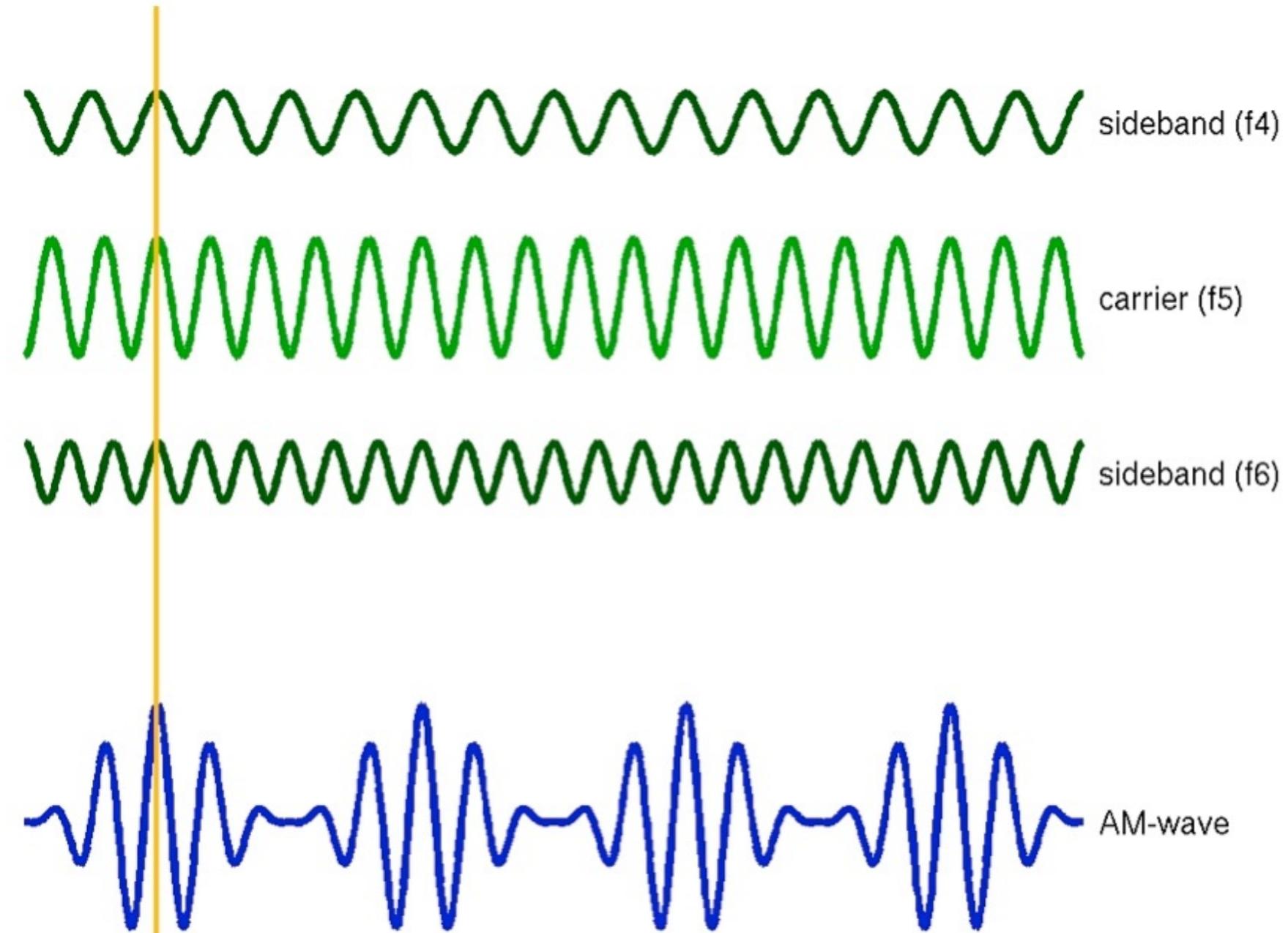
AM stimulus



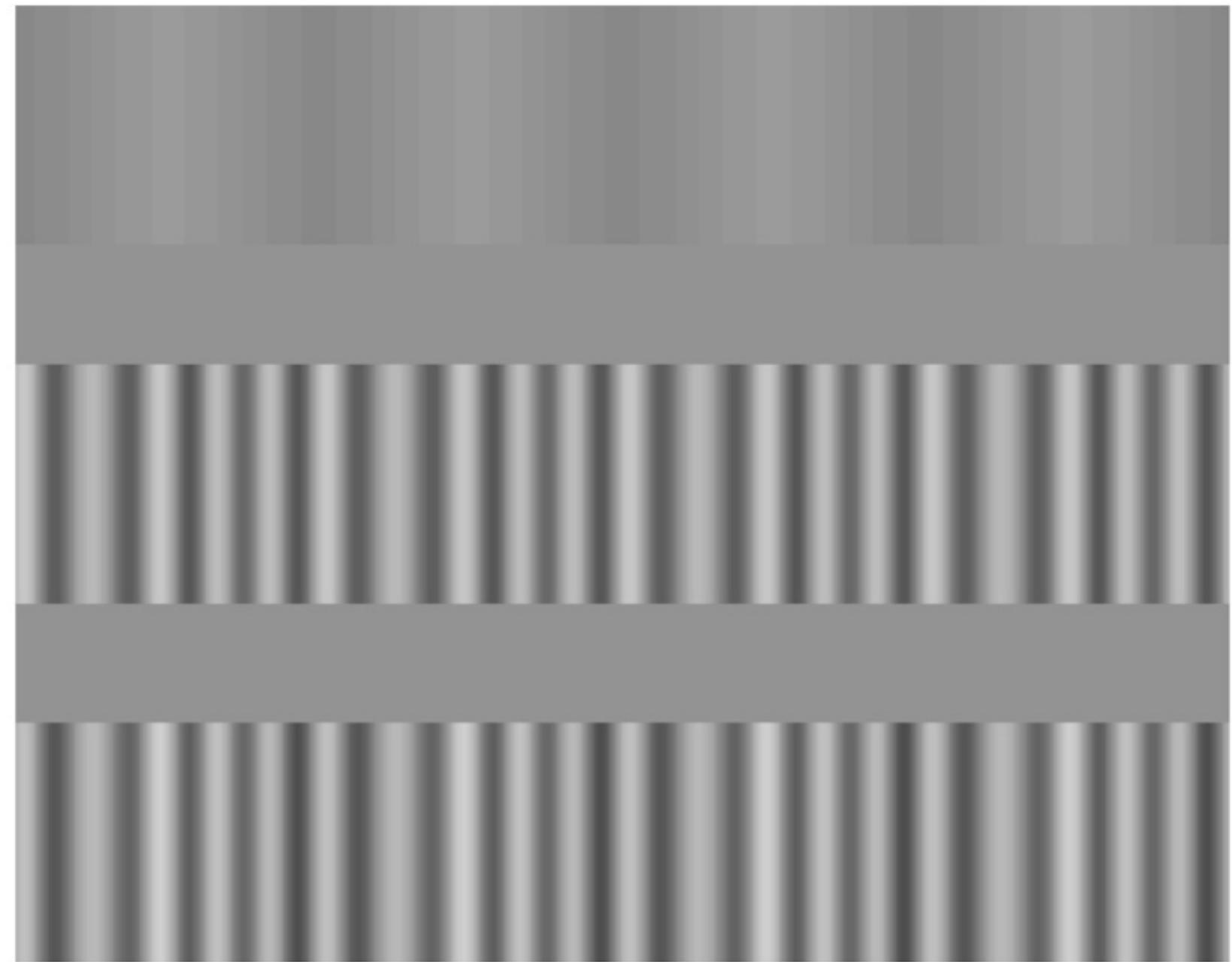
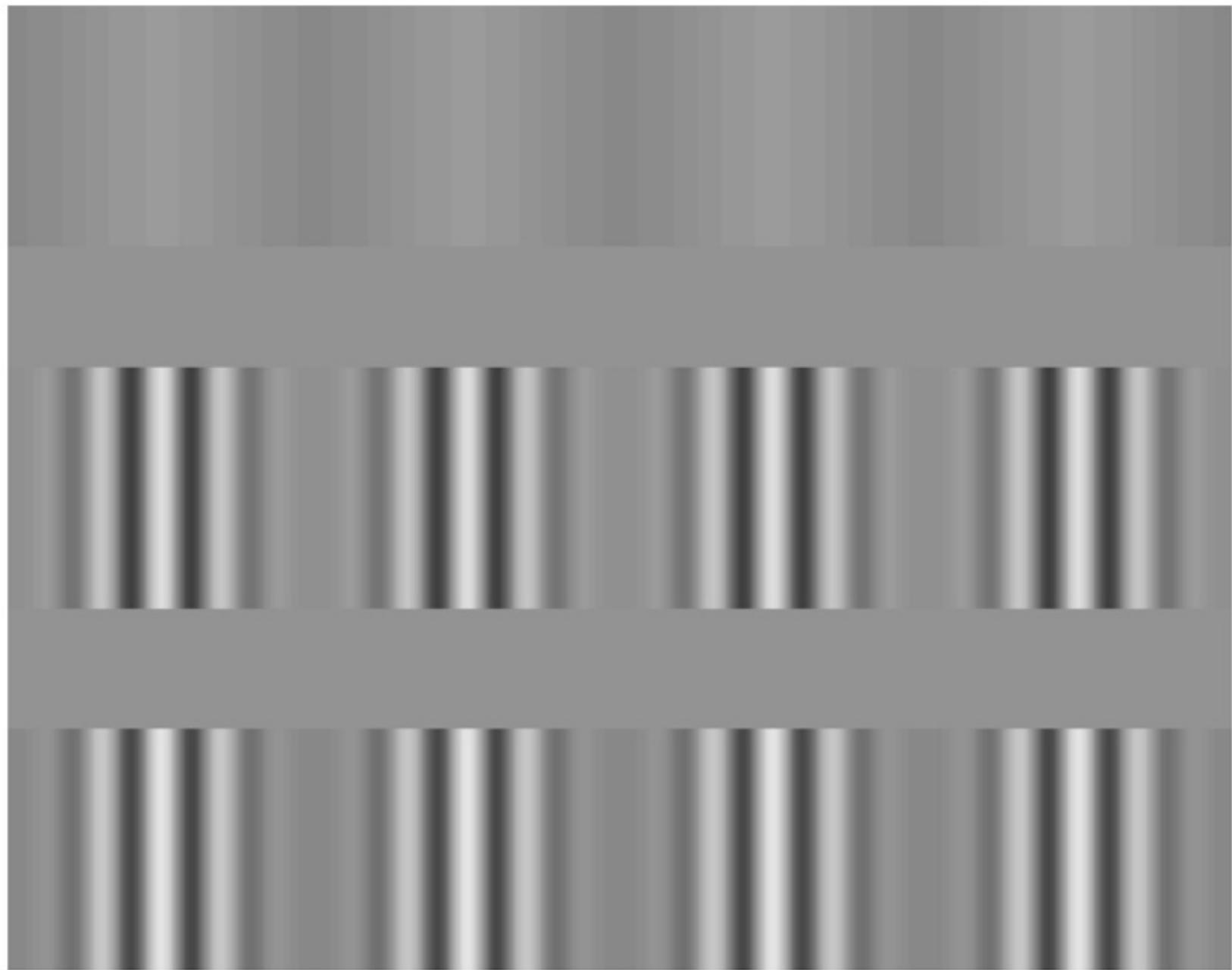
QFM stimulus



Cross-sections and amplitude spectrum of AM and QFM



Masking study: how does it look like?



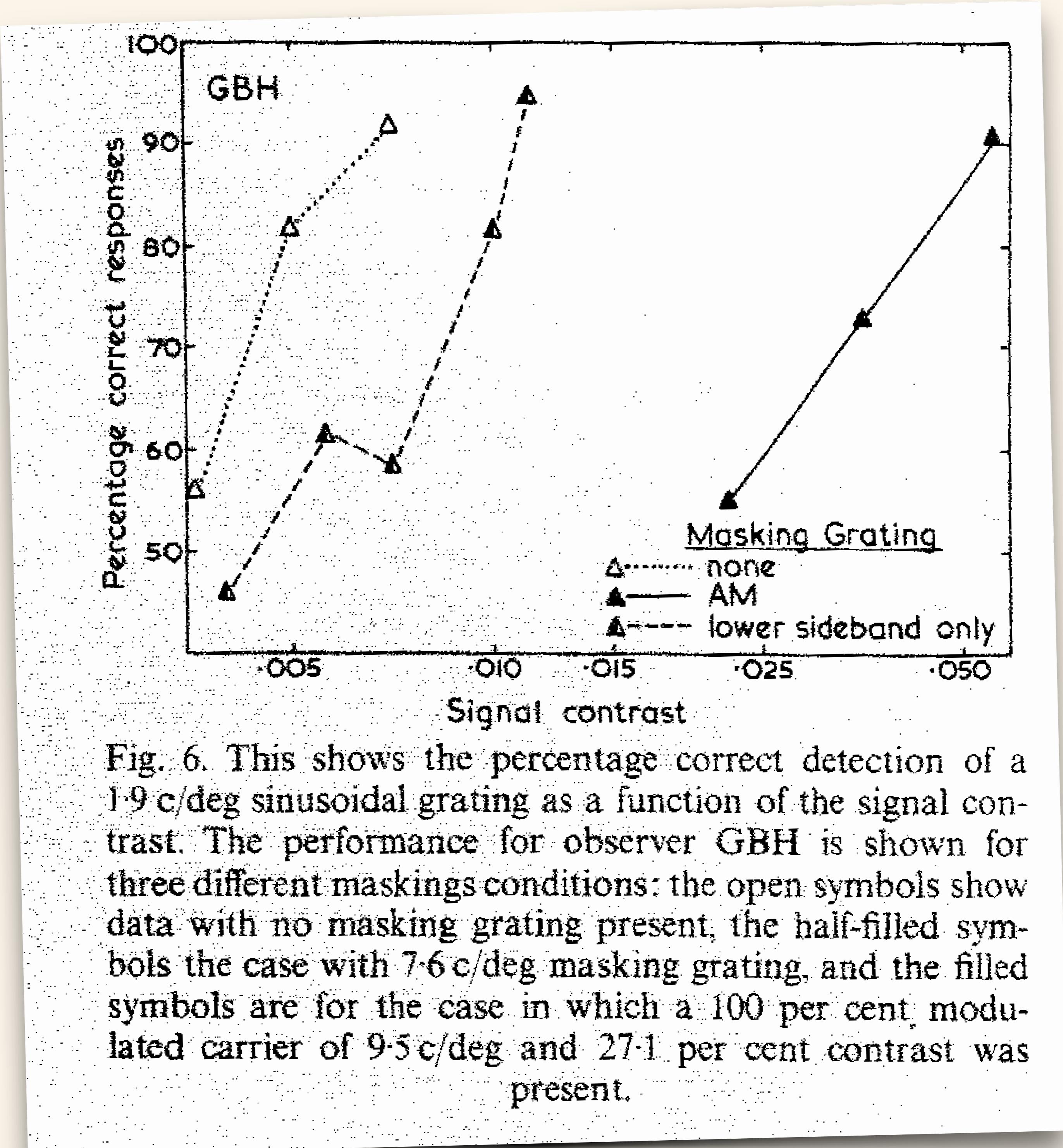


Fig. 6. This shows the percentage correct detection of a 1.9 c/deg sinusoidal grating as a function of the signal contrast. The performance for observer GBH is shown for three different maskings conditions: the open symbols show data with no masking grating present, the half-filled symbols the case with 7.6 c/deg masking grating, and the filled symbols are for the case in which a 100 per cent modulated carrier of 9.5 c/deg and 27.1 per cent contrast was present.

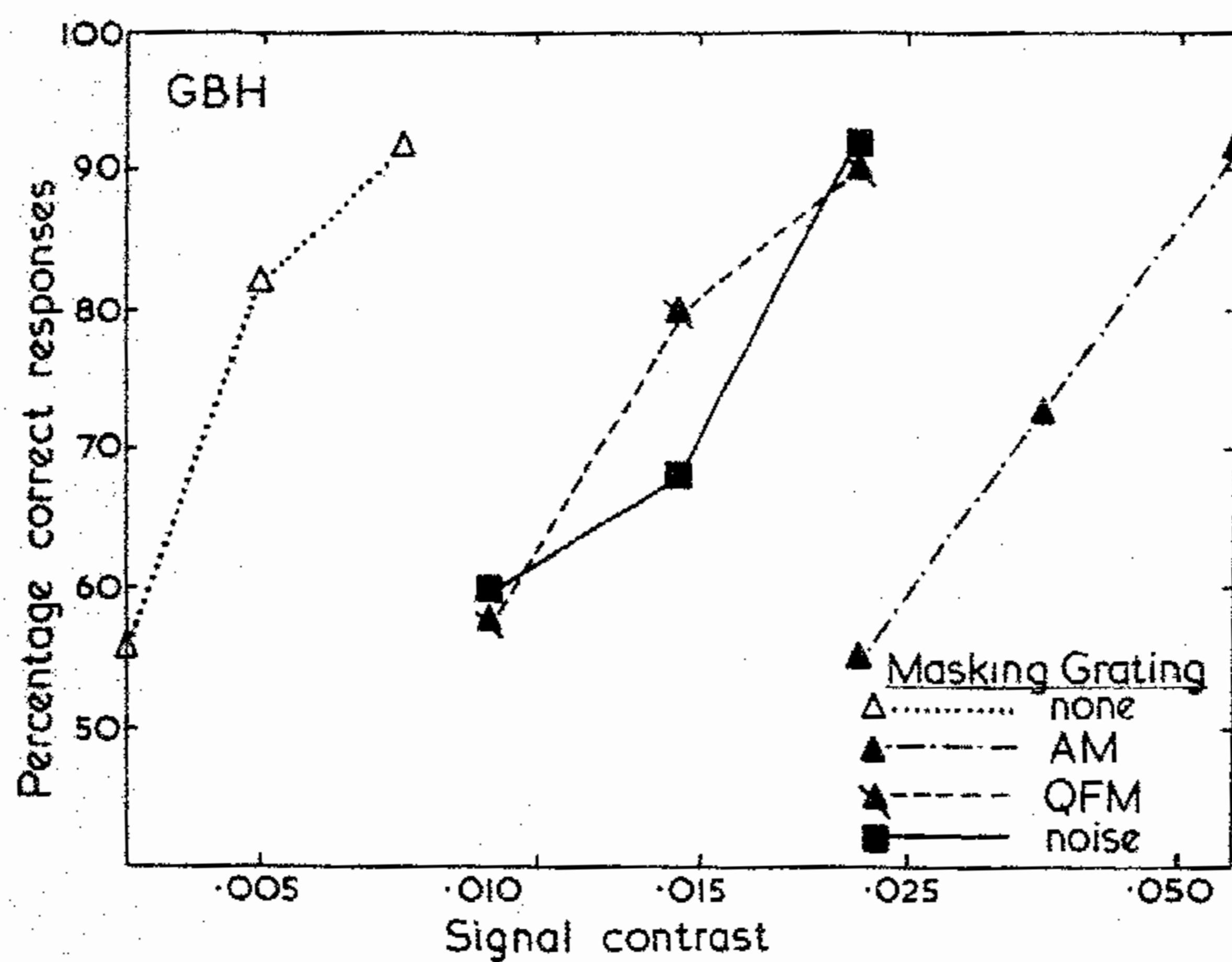


Fig. 9. This shows the percentage correct detection of a 1.9 c/deg sinusoidal grating as a function of the signal contrast. Data for experiment 2 with no masking grating (open symbols) and a 100 per cent contrast modulated masking grating are shown together with the data for the "quasi-frequency modulated" masker (symbols with a stroke through them) and noise band masker (square symbols).

Evidence for the Standard Early Spatial Vision Model

- Plenty of evidence for the linear-nonlinear-channels model ...
- ... **but** at the same time there exist a number of crucial experiments the model does not predict at all:
Henning et al. (1975) as discussed, and Derrington & Henning (1989) as discussed in Wandell (1995) are perhaps the most important and, arguably, the most elegant.

The End

Felix Wichmann



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