

Chapter 1 : UC Irvine Faculty

Higher-Order Processing in the Visual System Chairman: Michael Morgan *The task of the earliest stages of visual processing, in the retina, lateral geniculate nucleus and primary visual cortex (V1), is to represent the optic array in a sufficiently economical yet rich form for subsequent neural analysis to permit 'seeing'.*

Articles and Chapters Norman, M. Proceedings of National Academy of Sciences, 62, A test of single-channel and multiple-channels models. Vision Research, 11, Effects of luminance and pattern drift rate. Vision Research, 12, Vision Research, 13, Proceedings of National Academy of Sciences, 70, Vision Research, 16, Vision Research, 17, Vision Research, 18, Trends in Neurosciences, August, , pp Detecting edges without edge detectors. In Visual Coding and Adaptability, C. Vision Research, 21, In Perceptual Organization, M. Vision Research, 22, Perception and Psychophysics, 33, Vision Research, 24, 9, Graham, N. Optical Society of America A, 2, Attention and Performance XI pp. Probability distributions and combination rules. Mathematical Psychology, 31, Physica Scripta, 39, Testing a simple spatial-frequency channels model. Perception and Psychophysics, Effects of sign and amount of contrast. Vision Research, 32, Graham, N. The merging of two traditions. Orientation selectivity of complex channels. Ophthalmic and Physiological Optics, 12, Current Directions in Psychological Science, 1, Vision Research , 33, 14, Testing a computational model of light-adaptation dynamics. Vision Research, 36, 10, E, and Chase, V. A test of models of light-adaptation dynamics. Vision Research, 37, 9, A possible physiological explanation based upon a recent computational model. Visual Neuroscience, 15, Contrast-gain control in simple Fourier and complex non-Fourier pathways of pattern vision. Vision Research, 40, Vision Research, 41, Journal of the Optical Society of America A, 18, Visual Neuroscience, 18, Graham, N and Wolfson S. Vision Research, Wolfson, S. A test of a model relating V1 activity to mfVEP activity. Journal of Vision, 6, Forty-four years of studying light adaptation using the probed-sinewave paradigm. Exploring contrast-controlled adaptation processes in human vision with help from Buffy the Vampire Slayer. An unusual kind of contrast adaptation: Journal of Vision, 8, Wolfson, S and Graham, N Two contrast adaptation processes: Beyond multiple pattern analyzers modeled as linear filters as classical V1 simple cells: Useful additions of the last 25 years. One new, One Old. Spatial characteristics of a contrast-comparison process. Is the straddle effect in contrast perception limited to 2nd-order spatial vision?

Chapter 2 : Formats and Editions of Higher-order processing in the visual system. [calendrierdelascience.c

edited by GREGORY R. BOCK and JAMIE A. GOODE, Chichester, UK, John Wiley & Sons, \$ This volume will provide the reader with an excellent glimpse of current research concerning functional aspects of visual processing in the retina and brain.

Page 23 Share Cite Suggested Citation: Advances in the Modularity of Vision: The National Academies Press. A simple example can be found in Figure IN This is a black and white image that starts out as millions of bits of information about gray-level intensities that are encoded within the retina. What happens, literally in a split second, is that the brain processes that information and yields a rich and vivid set of perceptions. In particular, we perceive a human face. Moreover, by automatically comparing this face with the enormous number of images viewed over a lifetime, we recognize it as a unique individual- Albert Einstein. What is equally impressive is that a vastly degraded and simplified image Figure IB is also immediately recognized as Einstein. This is something that no computer vision system as yet can come even remotely close to achieving not because computers inherently lack the computational power to process the image, but because they have not been programmed with the right strategies for processing this information. The issue for this symposium, then, is the specific strategies used by the visual system to carry out such elegant analyses of the immense variety of images that we confront during normal vision. My remarks concentrate on the macaque monkey. Monkeys have been chosen because their sense of vision is very similar to that of the human in a variety of important and basic ways. About 95 percent of those are rods, which are used for night vision. Thus, there is already a great deal of convergence within the retina. That convergence is handled very elegantly by putting a high density of cones and retinal ganglion cells to subservise the fovea. In the center of the fovea there are 10, or more ganglion cells subserving each square degree of the visual field. Another important point about the output from the retina is that retinal ganglion cells can be subdivided into major cell classes. In primates, the subdivision is a basic dichotomy between approximately 10 percent of the cells that are very large neurons with large dendritic trees, termed the magnocellular population. These are distinct from the majority 90 percent of the ganglion cells, which are of the smaller and termed the parvocellular subtype. It is the parvocellular neurons that send high-acuity information, including information about color. Parvocellular neurons are generally associated with sustained responses to illumination. The magnocellular system, by contrast, carries little chromatic information and responds transiently to illumination. These two pathways head out from the retina and relay through separate layers of the lateral geniculate nucleus LGN. The magnocellular neurons of the retina terminate in the ventral-most pair of layers, while the majority of parvocellular neurons terminate in the uppermost layers. It receives the direct inputs from the LGN, and it contains a very precise and orderly representation of the opposite half of the visual field. In addition, there is a much larger belt of tissue, the extrastriate visual cortex, much of which is buried in one or another of the assorted folds of the cortex. At one time, it was thought that the visual cortex occupied only the occipital lobe. From studies done in a number of laboratories, however, it is now clear that visual cortex extends well down into the temporal lobe the inferior temporal region and well up into the posterior parietal region. How is this belt of tissue organized? The location of different areas are indicated on a drawing of the right hemisphere upper left and on an unfolded Dimensional cortical map center. Areas that have been particularly well-studied are shown in stippled: Van Essen and Anderson with visual processing in the cortex. It is now clear this was a vast oversimplification. In a two-dimensional unfolded map of the cerebral cortex in the right hemisphere of a macaque monkey, one can see more than two dozen different visual areas occupying the entire posterior left half of the hemisphere. For simplicity, only a few of these areas the stippled ones have been labeled in Figure 2. Many of these are well-defined areas that nearly all laboratories agree on, although not everyone uses exactly the same terminology. Although substantial number of regions are less well-defined, there is reasonable evidence that they represent distinct subdivisions. It is difficult because the criteria for identifying

these different subdivisions vary considerably. In general, visual areas in the cerebral cortex have been identified by a combination of criteria, the most important of which is that each area has a distinct pattern of inputs from other cortical areas and outputs to other target areas. Most of these areas have maps of the contralateral half of the visual field, which is accordingly represented over and over again. The maps are themselves an important part of the identification process. There is a lot of individual variability, however, in the detailed organization of these areas from one animal to the next. Although this is of interest in its own right, it also contributes to the difficulty of working out the arrangement of different areas. Studies in a number of laboratories have shown that connections within the visual cortex are nearly always reciprocal in nature. If area A projects to area B. Several research groups have noted this asymmetry and have suggested that direction could be associated with forward or ascending information flow, whereas flow in the opposite direction is viewed as feedback. Based on these anatomical criteria, John Maunsell and I Van Essen and Maunsell, suggested several years ago that the overall collection of visual areas could be grouped together into an anatomically based hierarchical scheme that starts with area V1 and then goes through a half dozen separate layers until one gets to higher-level processing centers in the temporal, frontal, and parietal lobes. An important question is how high into cortical processing centers this scheme remains valid. There is now enough evidence to trace the succession of processing centers all the way from the retina up through visual areas in the occipital, temporal, and parietal lobes, all the way up and out of visual cortex proper in fact, out of neocortex and into the hippocampus. In our current version Dan Felleman and I have proposed a dozen stages of hierarchical processing in the cortex, plus an additional pair of stages represented by the retina and LGN. This, then, gives us a sense of the degree to which information goes through successive hierarchical levels, and also of the rich degree of parallelism and reciprocity in terms of multiple outputs from any one area to targets at both higher and lower levels. V1 is the largest of all visual areas; V2 is nearly as large and adjoins V1. The cortex, when sliced parallel to the cortical surface and stained with the mitochondrial enzyme cytochrome oxidase, reveals a distinctive pattern. These patches are separated by so-called interblobs which stain less densely for the same enzyme. At the border between V1 and V2, a rather different configuration is evident orthogonal to the boundary between the areas. The darkly stained regions have a different connectional pattern than the more lightly stained region, and both of these differ from a third compartment of pale interstripes, all within area V2. Experiments we have conducted show that when fluorescent tracers were injected into the target areas MT and V4, we were able to identify cells projecting to MT located primarily in the thick stripes, with a much lower number and some cells in the thin stripes as well. We also identified cells projecting off to area V4 that are concentrated in both the thin stripe and the interstripe regions. There appears to be a dichotomy in the retinal and geniculate organization. The magnocellular and parvocellular subdivisions project to separate portions of area V1. The magnocellular projects to its own layer, area layer 4C, which in turn projects to layer 4B. That is one discrete compartment. In areas V1 and V2 there is a tripartite compartmentalization. Layer 4B of V1 and the thick stripes of V2 are dominated by magnocellular inputs, and they project most strongly to area MT and from there to the posterior parietal complex. The blobs and interblobs of V1 and the thin stripes and interstripes of V2 are dominated by parvocellular inputs, and information flows from them to area V4 and then to the inferotemporal complex. All lines except that from the retina to the LGN represent reciprocal connections. Note that there is significant cross-talk between processing streams at several levels of the hierarchy. There is further segregation of these streams with the thick stripes as well as layer 4B projecting both to area MT and V4 receiving inputs not just from one stream but from both of these together. The standard approach inspired by the work of Hubel and Wiesel is to use simple stimuli such as bars and edges of light, and to ask what turns on a cell in any given area. Figure 4 shows an example of a cell from area VP, which happened to be highly selective for stimulus wavelength. The cell responds to long wavelengths, i. There is now quite a rich catalog of information of the basic selectivity of cells in the visual pathway, based on studies in many laboratories. We know, for example, that color selectivity is very common in V4, but is very rare in MT. Interestingly, the same distinction applies to the different compartments of area

V2. Those compartments projecting off to MT have very low color selectivity, whereas both of the thin and interstripe compartments that project off to V4 are rich in color selectivity by our criteria. The opposite is evident when looking at direction selectivity. Here there is a high incidence of direction selectivity in area MT and very low in area V4. A similar bias occurs in that there is a very low incidence of direction selectivity in the V2 compartments projecting to V4 and a somewhat higher incidence in the thick stripes that project off to MT. But it is not a perfect match, in that the percentage of direction selective cells in the thick stripes of V2 is not nearly as high as the actual percentage for MT. One has to wonder what is going on in this compartment other than a simple analysis of stimulus direction. Using this kind of information, again gleaned from a number of different studies, Ted DeYoe put together an illustration to give a qualitative impression of the kinds of information processing represented within the different channels that we have seen. In the magnocellular stream, for example, projecting through V1 and V2 into MT, there is a substantial incidence of direction selectivity, suggesting an involvement with motion analysis. There is also information about stimulus orientation and binocular disparity represented at all these levels. So it is not just a single kind of selectivity. Multiple cues appear to be analyzed within this stream. Within the parvocellular stream, the compartments associated with the blobs and the thin stripes are dominated by an analysis of wavelength; one suspects that it is involved in the analysis of stimulus color. IL, t-", RED 1. The cell responds well to long wavelengths red but not to shorter wavelengths or to white light. Of color-selective cells and orientation selective cells, many cells showing selectivity along both dimensions. This raises a question of whether there is a real difference in the way in which color wavelength information is used in these two streams. Icons are placed in each compartment to symbolize a high incidence of cells showing selectivity for stimulus wavelength prisms, orientation angle symbols, direction pointing hands, or binocular disparity spectacles. Each processing stream has a distinctive physiological profile, but most types of selectivity are representative in more than one stream. Once the information about the presence of a border has been generated, however, information about the colors used to define the border might be discarded higher in the system. Thus, the presence of wavelength selectivity per se does not in and of itself imply that it is part of the stream explicitly involved in color analysis. That raises a fundamental question about what these higher-order areas are actually doing. Neurons in these areas are not simply relaying information; they must also be processing the information in an interesting way. We suspect that the answer does not lie in the way in which simple stimuli are analyzed. More complicated stimuli are needed to understand the role of these cells. The type of stimulus complexity that is needed should be linked to the tasks of the visual system in mediating perception.

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Then I did a brief stint in biophysics before discovering physiological psychology and, at last, perceptual and cognitive psychology. I received my Ph. My goal then, as now, was to apply the quantitative and theoretical methods of the hard sciences to the analysis of cognitive processes. More recently, Adam Reeves and I developed a mathematical theory for temporal attentional filtering, and a corresponding psychophysical method for measuring shifts of visual attention. Erich Weichselgartner and I exploited these methods to show that movements of attention across the visual field are quantal not analog, and to measure the different dynamics of automatic and controlled attention. We also developed a general method for measuring the time course of almost any perceptual event, and applied it to the perception of extremely brief flashes. Shui-I Shih and I developed a paradigm to show that early attentional filtering in search tasks, which is possible for space or time, works indirectly for physical features such as "colors", by enhancing processing at the locations and times at which attended colors occur. Steve Wurst, Zhong-Lin Lu, and I studied how attentional filtering in many feature dimensions and in combinations of dimensions can control the input to short-term memory. Revisiting an early theme, Karl Gegenfurtner and I worked out a computational model for the acquisition and decay of items in iconic memory. Jan van Santen and I developed a mathematical theory based on elaborated Reichardt detectors to account for many of the essential phenomena of classical motion psychophysics. Then, Charles Chubb and I discovered motion displays that would be invisible to all motion detector mechanisms that had thus far been proposed, including Reichardt detectors. With these displays, we identified second-order motion and pattern perception systems not known previously, work that continued with Joshua Solomon and Peter Werkhoven. Recently, Zhong-Lin Lu and I developed a "pedestal" paradigm that enabled us to isolate and characterize the three visual motion-perception systems that operate simultaneously in human perception. Other projects, with many collaborators, involved dynamic image processing of American Sign Language to enable it to be transmitted on ordinary telephone channels. In teaching, I noted that precisely the same optimization computation is used in signal detection theory and in resource theories of attention. Barbara Doshier and I found that a similar optimization theory applies to cognitive strategies in information-processing tasks. Some of the projects listed above have yielded such detailed flowcharts of "cognitive microprocesses" that it seemed it might be possible to localize these processes in the brain. The focus has been the identification of brain mechanisms of motion perception and attention. I discovered early that collaborative research is the most fun, and my current research continues the themes in vision and attention with student, postdoctoral, and faculty colleagues. The Human Information Processing Laboratory, where these projects are carried out, offers computer facilities for almost any project in perception or cognition. Students learn about cognitive science and also acquire facility with computer systems, with complex, modern experimental techniques, and with methods of modeling and formal theory construction, and develop the diverse technical skills they need to work at the forefront of knowledge. The information available in brief visual presentations. Current Contents, , 21, Historical background of this research. American Psychologist, , 44, Review Articles indicates "pdf download, may require Macintosh Acrobat 5. A brief overview of computational models of spatial, temporal, and feature visual attention. Invariances in Human Information Processing. Routledge, Taylor and Francis Group. Three-systems theory of human visual motion perception: Two computational models of attention. A century of human information-processing theory: Vision, attention, and memory. A systems analysis of visual motion perception. Episodic theory of the dynamics of spatial attention. Psychological Review, , Full-wave and half-wave processes in second-order motion and texture. In Higher-order processing in the visual system. Wiley Ciba Foundation Symposium, Three stages and two systems of visual processing. Spatial Vision, 4 [Prazdny Memorial Issue], Strategy and optimization in human

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