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13. ABSTRACT *(Maximum 200 words)*

Our goal is to understand the neural basis of perception and to test computational models of visual processing. This year we have been pursuing 3 lines of research: a) we have been continuing our earlier studies on 'motion capture', shape from shading and stereopsis. Our research suggests that image segmentation (based on texture, occlusion can) profoundly influences the early visual processing of stereopsis, shape from shading and motion correspondence; b) we have begun to investigate the 'filling in' of 'artificial scotomas' and of scotomas produced by brain injury. (Our goal has been to understand surface interpolation), and; c) we have developed a new psychophysical technique for isolating and studying a "fast" contour system in human vision; a system that might correspond to the magnocellular pathway of physiologists.

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Summary of Research Projects (V. S. Ramachandran/AFOSR)

Our lab has been continuing our earlier studies on shape from shading, "motion capture" and structure from motion (described in our annual report last year). This year we have also begun two new projects which I will describe here.

1. *Perceptual "filling in" of scotomas.* Patients with damage to the visual cortex are ordinarily unaware of their scotomas. It is usually assumed that the scotoma gets "filled in" by the texture and color from the surround. What are the spatial and temporal constraints on this "filling in" process? And what are the underlying neural mechanisms?

The importance of the "filling in" process derives from the fact it is a manifestation of a normal visual process called surface interpolation. (It is unlikely that the visual system has evolved mechanisms specifically to cope with scotomas!) When you look at any visual scene the visual system probably begins by using outlines to create a set of "cartoon sketches" of the image and then proceeds to "fill in" the surface attributes. It is this process that one is tapping into when studying the filling in of scotomas.

We have been studying filling in in four situations:

1. The natural blind spot;
2. "artificial" scotomas induced by adaptation;
3. scotomas caused by laser induced retinal lesions;
4. scotomas produced by damage to the visual cortex.

By comparing "filling in" in these four situations we hope to gain a novel insight into the neural mechanisms underlying surface interpolation.

Our results are described in the two enclosed papers. (One is in press for the May issue of *Scientific American* and the second is being submitted to *Nature*.)

Personnel involved in these studies include:

1. Dr. Diane Rogers-Ramachandran, post-doctoral fellow;
2. Daniel Plummer and Steven Cobb, graduate students

2. *"Phantom contours":* Separate neural mechanisms for seeing surfaces and seeing contours. These experiments are being conducted by Dr. Rogers-Ramachandran. there are computational (e.g. see Grossberg et al) and physiological (e.g. see Livingstone & Hubel) reasons for believing that when you look at an object its outline and its surface attributes (e.g. color/texture) are extracted by separate pathways. We now present new psychophysical evidence for the existence of such a distinction. (See enclosed summary from a recent book chapter and enclosed videotape of "Phantom Contours.") The videotape is being shown later this week by Dr. Diane Rogers-Ramachandran at the Simon and Fraser annual conference on vision (Vancouver, British Columbia).

RE: Spatial and Temporal Interpolation in Visual Object Recognition

This proposal by Dr. Phillip J. Kellman raises some interesting questions and certainly deserves to be considered for funding by the Airforce. I shall discuss two aspects of the proposal:

a. Both illusory contours and "amodal" contours are striking perceptual effects but until recently interest in them has been confined mainly to psychologists. Fortunately, during the last 10 years or so there has been a tremendous resurgence of interest in these effects among both AI researchers and neurophysiologists. Most of the work in the field, however, has been of a phenomenological nature (e.g. see the stunningly beautiful demonstrations in Kanizsa's book). Although these demonstrations were very instructive we also need systematic psychophysics and Dr. Kellman's proposed experiments may help fulfill this need. Many of his experiments are designed to explore the spatial and temporal constraints on these two processes.

b. Dr. Kellman also believes that these two visual effects - illusory contours and "amodal contours" are based on a "common underlying process," and many of his experiments are designed to explore this possibility. Personally, I don't find this aspect of his proposal especially interesting. It is not clear to me what exactly the author means by "common underlying process." Given the obvious fact that both these phenomena are concerned with *interpolation* of contours it is hardly surprising that there are many similarities between them but the mere existence of similarities does not establish that there is a common mechanism. (For example, there are many similarities between apparent motion and stereopsis but one wouldn't want to argue that these two phenomena have a common underlying mechanism.) Also, there are many displays in which the perception of illusory contours actually "vetoes" or excludes amodal contours and *vice versa* (e.g. see recent article by Nakayama et al on "neon spreading" and stereopsis in *Perception*). And finally, I seem to recall that illusory contours disappear at equiluminance whereas amodal completion remains essentially unaffected.

Let me add, however, that these objections do not in any way detract from the value of the authors proposed experiments. There is hardly any systematic psychophysics on illusory contours and so <u>any</u> data would be valuable. Indeed, many of the author's experiments are very cleverly designed to explore the information processing strategies underlying the perception of illusory contours - a subject about which very little is known.

Qualification of the Research Team

The PI, Dr. Kellman, has a long record of publication in this field. He is a competent and skilled investigator.

Overall competence: top 30%.

Last year's Annual Progress Report; Grant NO. AFOSR 89-0414

Personnel involved:	Dr. Vilayanur S. Ramachandran, Professor
	Dept. of Psychology Neuroscience Program Cognitive Sciences Program Institute for Computational Neuroscience
	Dr. Diane Rogers-Ramachandran, Research Associate (50%) Dr. Margret Sereno, Postdoctoral fellow (50%) Dorothy Kleffner, Graduate student Daniel Plummer, Graduate student

Publications, Lectures, etc. (1989-90)

Ramachandran, V.S. (Nov. 1989).
Visual Perception in People and Machines;
Presidential Lecture given at the Annual meeting of the Society for Neuroscience. (Phoenix, Arizona).

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Visual heuristics. Public lecture, 225th Anniversary of the University of Pennsylvania School of Medicine.

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Visual Perception in People and Machines;
A. Blake and T. Troscianko Ed.
AI and the Eye, J. Wiley and Sons, Bristol, UK.

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Interactions between motion, depth, color and form in C. Blakemore ed.
'Visual Coding and Efficiency; Lectures in honor of H. Barlow',
Cambridge University Press, Cambridge and New York.

Ramachandran, V.S. and Diane Rogers-Ramachandran (1989)
Occlusion and Transparency in Motion Perception. Soc. for Neuroscience Abstracts.

Stoner, G., Albright, T. and Ramachandran, V.S. (1990)
Transparency and Coherence in Human Motion Perception.
Nature, *344*, 153-155.

Treisman, A., Cavanagh, P., Ramachandran, V.S. and R. Van Der Heydt. (1990)
Form perception; Striate cortex and beyond. in L. Spillman and J. Werner ed. "Visual Perception; Neurophysiological foundations". Springer-Verlag, Berlin.

Diane Rogers-Ramachandran and V.S. Ramachandran, (1989).
'Motion Capture and Motion Contrast', 11th. ECVP. (European Conference on Visual Perception), Bristol, England.

V.S. Ramachandran and D. Kleffner, (1989).
Interaction between color and motion in human vision. ECVP, Bristol, England.

V.S. Ramachandran, H. Pashler, and D. Plummer, (1989).
2-D or not 2-D; That is the Question.
Psychonomic Society Annual Meeting.

D.J. Plummer, V.S. Ramachandran, and H. Pashler, (1990).
Pre-attentive pop-out of 3-D image features - The role of Size constancy, ARVO.

V.S. Ramachandran and D. Kleffner, (1990).
Interactions between motion, position, and 'texture' in human vision, ARVO.

D. Kleffner, V.Polichar, and V.S. Ramachandran, (1990).
Shape from Shading affects motion perception and brightness constancy, ARVO.

Forthcoming Publications:

Nakayama, K., Shimojo, S., and Ramachandran, V.S. (1990).
Illusory contours, 'neon-spreading' and stereoscopic depth, Perception, in press.

V.S. Ramachandran, "Visual Perception" Book in preparation for the Scientific American Library Series, Freeman and Co., New York.

V.S. Ramachandran and Patricia Churchland.
"Brain and conscious experience". Book for the Scientific American Library Series, Freeman and Co., New York.

V.S. Ramachandran and S.M. Anstis, (1990).
"Illusory motion and displacement of equiluminous kinetic edges", Perception, in press.

Overview of Research Goals

Our research during the last 2 years has been concerned mainly with the perception of motion, stereopsis, and shape-from-shading, and, especially, with interactions between these processes. We have been using mainly psychophysical techniques but our results have inspired several new computational models and lead to interesting proposals for physiological experiments at the single unit level. Indeed one of our goals has been to develop conceptual links between psychophysics, physiology and AI - three disciplines which are now beginning to show some promise of convergence, (Ramachandran, 1989). The UCSD campus is an ideal place for such convergence to occur since we can draw upon the expertise of individuals working on all these different aspects of vision. (eg. Psychophysics-R.M. Boynton, D.I.A. MacLeod, and D. Rogers-Ramachandran;

Physiology-T. Albright, Marty Sereno, G. Baylis; Computational Models-T.Sejnowski, D. Zipser, Margaret Sereno, P. Kuby; Theoretical Approaches-F.H.C. Crick and Pat Churchland).

Our lab works in close association with Dr. Albright's group at the Salk and some of the Dr. Albrights graduate students (especially G. Stoner and K. Dobkins) have already started looking for physiological correlates of visual illusions that have been discovered in our lab. We have also begun some collaborative PET studies (on awake human patients) with Dr. M. Raichle and Dr. Steve Petersen at the University of Washington (St. Louis). Two major conclusions have emerged from our psychophysical work.

1. For solving any given computational problem (e.g. motion correspondence, structure from motion, stereopsis, the aperture problem, etc.) the visual system seems to use multiple parallel heuristics instead of a single sophisticated algorhithm. Our goal will be to identify these heuristics and find out what particular natural constraints are being exploited by them. The advantage of using multiple mechanisms, of course, is that they enable the organism to tolerate noisy (even camouflaged) images of the kind it would normally encounter in the natural world.

2. Our second major conclusion concerns the important role of image segmentation in visual perception. AI researchers (especially David Marr) have tended to regard segmentation as a separate and more complex problem from what they call 'early vision' - i.e. stereopsis, motion correspondence shape from shading, etc. But our research suggests that this view needs to be revised. Segmentation based on various cues such as occlusion (e.g. illusory contours) can profoundly influence the early processing of motion, stereopsis and shading (Ramachandran, 1989c). A similar point has also recently been made by Ken Nakayama (Harvard). This implies that they must be a great deal of "cross talk" between difficult visual modules. The numerous reciprocal cross-connection described by David Van Essen provide a suitable substrate for mediating these interactions.

I will now describe some of the projects that were begun in 1989 and will consider how they illustrate the ideas I have outlined above.

Motion Capture.

If moving illusory contours are superimposed on a grid of stationary dots the dots also appear to move in the same direction. This is one example of a new class of effects that we have dubbed 'motion capture'. (Ramachandran and Inada, 1985; Ramachandran, 1990a, 1990b). The unambiguous motion signals derived from certain salient features in the images (e.g. in this case the illusory contours) are blindly attributed to any finer stimulus features in the vicinity. Numerous computational models have been proposed recently to account for these phenomena (e.g. Bulthoft et al, 1989, Nature, *337*, 549-553; Yuille and Grzywacz, 1988, Nature, *333*, 71-74; D. Gilden, 1990, ARVO; Grossberg, 1990, ARVO).

Another example of this effect can be seen if sparse black dots are optically superimposed on a yellow square that is displayed against an equiluminous grey background. when the spots are moved the yellow square also appears to move in the same direction. (Ramachandran, 1990a).

Conflicts between 'motion' and 'position' signals.

If the black spots are moved continuously - as in a conveyor belt - the yellow square does not move continuously. Instead, it appears to move for a short distance and 'jumps back'. This illusion arises because even though the motion system is fooled into thinking that the square is moving, there is another system that simultaneously informs the brain that the location (or position) of the square has not changed.

We discovered that if a whole horizontal row of squares is used instead of a single square then the whole row does indeed appear to move continuously. By adjusting the spacing between the squares we were able to measure the sensitivity of the 'position' system. (Ramachandran and Kleffner, ARVO; 1990).

Selective attention modulates motion capture.

We begin with a random matrix of 7 spots on the CRT - switch them off and replace them in Frame 2 with the same 7 spots shifted horizontally by about 1°. (Figure 12). The 2 frames are cycled continuously so what you see is continuous left-right oscillation of the spots. We then simply take an opaque piece of masking tape and paste it on the CRT so that it completely occludes one of the spots in frame 2. (The spot if still visible in frame 1, of course). Not surprisingly you continue to see the spots in the surround oscillate as before but the remarkable thing is that the single unpaired spot also continues to oscillate - it moves behind the tape even though its partner in frame 2 is invisible. If you have two bits of tape - one on each side of the unpaired spot - the spot always "chooses" to move behind the one on the right.

What causes this illusion? Well, perhaps the motion system - the magno-MT system - 'sees' all 7 spots as one big blob and extracts the motion signal from the whole blob without resolving the individual spots. The motion signal is then blindly attributed to all the finer features in the images - including the single unpaired spot in the middle - so that it appears to move as well ('motion capture').

Diane Rogers-Ramachandran used this display to explore the effects of visual attention. Instead of having a single set of 7 spots she had two sets of spots moving in opposite directions. If the conditions are right then what you see is two planes of spots - moving in opposite directions, the dots being grouped together by "common fate". (You can also voluntarily focus your attention on one plane alone and exclude the other.) But what if you now add a single unpaired spot in the middle that has no partner in frame 2? (Of course, you also provide two bits of masking tape - one on either side of it.)

Does the single spot then appear to move leftward or rightward? Or do the motion signals from the 2 oppositely moving planes of dots just cancel each other - so that you don't see any motion in the unpaired spot? The answer is, it depends on what you attend to. If you attend to both planes of dots simultaneously - which is difficult but can be done - you do indeed see the single spot just blinking on and off without moving. But if you attend to one dot cluster alone the unpaired spot moves along with that cluster. If you attend to the rightward moving dots it moves rightward and if you attend to the leftward moving cluster it moves leftward. This is really quite remarkable for it suggests that motion capture can be strongly modulated by visual attention - it cannot be based on a simple spread of motion signals from the moving elements to the unpaired spot.

Motion Coherence and Transparency.

Movshon and Adelson have shown that if two moving gratings are superimposed they will appear to cohere and move in a single direction ('pattern motion') instead of moving independently - (component motion). We have now discovered that this tendency to see pattern motion depends crucially on the luminance of the intersections (Stoner, Albright, and Ramachandran, 1990; Ramachandran, 1989c). Specifically, we find that when the two gratings luminances are multiplied (to mimic two physically transparent gratings or N.D. filters) then component motion is seen. Our hypothesis is that the motion system has tacit 'knowledge' of the physics of transparency.

One of our future goals will be to test this hypothesis further. We believe that other researchers in this field (there are over two dozen groups working on motion coherence) have missed this observation because they simply added the 2 gratings luminance and did not vary the intersection luminance separately.

We have also started exploring these phenomena at the level of single cells in MT. This will form part of Gene Stoner's Ph.D. thesis.

Shape-from-Shading.

Another line of research being pursued in our laboratory concerns shape-from-shading, (Ramachandran, 1988b). It is quite remarkable that since the time of Leonardo da Vinci (who first thought about this problem) there have been only two or three systematic studies on shape-from-shading.

Work in our lab suggests that shading is a primary visual dimension (like stereopsis, motion, color, etc.) and that it is probably extracted early in visual processing. (Kleffner and Ramachandran, ARVO, 1990; Ramachandran, Scientific American, 1988.)

We also find that the extraction of shape-from-shading is strongly affected by image segmentation - e.g. by illusory contours. Chromatic borders and texture borders are, however, ineffective.

Finally, we find that the motion system can use shading as an input. In collaboration with Tom Albright (Salk Institute) we are now trying to explore the physiological correlates of this effect by recording from direction selective cells in MT. It is known, for example, that these cells will respond not only to moving luminance edges but also texture-edges of the kind originally used by Ramachandran et al (1973) and G. Sperling in Psychophysical experiments. Would these cells also respond to motion that is defined exclusively by Shape-from-shading?

Visual Search in the Presence of conflicting Depth Cues.

An unsolved problem in Psychology concerns the manner in which information from different sources is combined in the brain to create a unified picture of the world. For example, the relative distances between objects can be conveyed by many different 'depth cues' such as perspective, stereopsis, shading and occlusion. How are these cues subsequently integrated to compute a 3-D representation of the world? We explored this by measuring reaction times for detecting targets in which different cues were either consistent or in conflict with each other. Results suggest that different depth cues are initially combined in a common "cue-invariant" 3-D representation of the world and that visual search for a salient target is carried out in this 3-D representation rather than at an earlier stage in visual processing. (Plummer, Pashler, and Ramachandran, ARVO, 1990; Ramachandran, Pashler, and Plummer, Psychonomic Society, 1989).