CHAPTER 11

Information created by movement

Introductory

The studies of blind-sight and unilateral neglect discussed in the last chapter show that visual perception is not the kind of thing that can be understood by introspection alone. Rather, it is the fruit of a labyrinthine concatenation of neural processes, involving activity in large variety of locations within the brain. The same message can be derived from the diagrams to be shown later (in chapters 14 and 15). These provide glimpses of a massively complex system containing a wide variety of neural structures, hundreds of millions of neurons and untold billions of connections between them. This chapter is grist to the same mill. It concentrates on the work of James Gibson, Nicholas Bernstein and Gunnar Johansson, three scientists who extended our understanding of the experience of seeing.

Although many might suppose that movement-generated perceptual cues could have little or nothing to do with drawing static objects from observation, they would be wrong, as made clear in my book on drawing.[1] *However, their usefulness in drawing practice is far from the only reason for devoting a whole chapter to them. Thus: Gibson created a new interest in the power of movement-generated cues, Bernstein used elegant mathematics to demonstrate the interdependence of top-down and bottom up influences in the control of visually guided movement, and Johansson produced a demonstration that blew away a multitude of misconceptions.*

James J. Gibson

The controversy-relishing J.J. Gibson made key contributions to the psychology of visual perception. He, more than anybody, directed attention to th e importance of the information provided by movement, either of the eyes relative to their environment or of the environment relative to the eyes. In the process, he challenged prevailing ideas concerning the nature of visual perception.

1 "*Drawing on Both sides of the Brain*"

On a more personal level, I would like to acknowledge the critical role Gibson's writings played in the development of my own ideas. His gift to me was not only due to the persuasiveness of his proposals and the invigorating atmosphere of challenge they brought into studies of the subject I was trying to understand. Just as important was the stimulus I got from plucking up the courage to disagree with some of his claims. In the chapter on my drawing experiments (*Chapter 7*), I explain why I reacted both against his belittling of traditional laboratory experiments and his offhand dismissal of the possibility that the study of paintings might provide useful information for students of visual perception. Also, throughout my books there is ample material to explain why I could not accept his belief that spending time thinking about what goes on inside the head is an unnecessary distraction. None of these rejections diminishes my appreciation of the good ideas that he shared.

Gibson and crash landings

During the *Second World War*, Gibson was asked to investigate the causes of the worryingly large number of pilots who crashed their aircraft in the course of landing on the airport runway. How could it be that so many highly trained pilots were failing to judge the crucial relationship between the wheels of the incoming plane and the surface of the landing strip? To answer this question he focused on the nature of the visual information being generated by the interaction between the pilot's eyes and the surface of the fast approaching runway. Knowing that high speeds cause the blurring of texture information, it was reasonable to suspect that the pilots might find difficulty in making use of it. Could this be the cause of the accidents? To find out the answer to this question Gibson had grids of yellow lines painted on the runway and waited to see what would happen to the pilots. Much to everyone's delight, the crashes stopped abruptly.

The pilots' problem was perhaps not too difficult to solve. Much more important for Gibson were the far reaching implications he derived from solving it. As a psychologist of perception, he could hardly have failed to realise that his solution constituted a fundamental challenge to the prevailing wisdom concerning visually mediated distance estimates. Hitherto, the tradition had been to do experiments in the laboratory, studying static viewers, looking at static targets. The dependence of the aircraft pilots on movement generated cues made clear that this way of doing things had important limitations. Thus, though from the point of view of the pilots the story was over, for Gibson and psychologists of visual perception, it was only just beginning.

Gibson's ideas

For a scientist, the fact that texture was the critical cue is certainly interesting, but much more so would be the discovery of how human visual system use the information it provides. Gibson's crucial idea was to look for invariants in the structure of the input to the eyes. What he found was that movement towards no matter what surface generated a particular pattern of texture transformation. Movement across a surface did the same thing. He called these "*flow fields*".

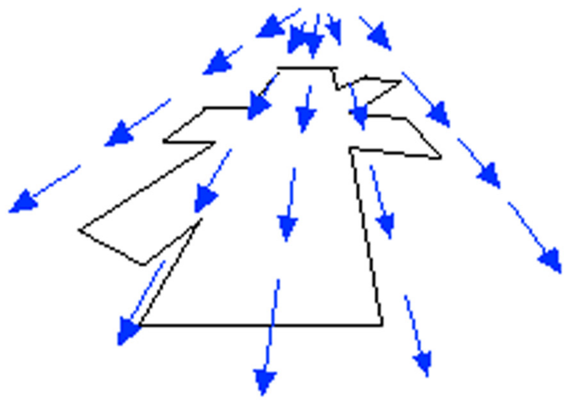

Figure 1 : flow field for normal approach.

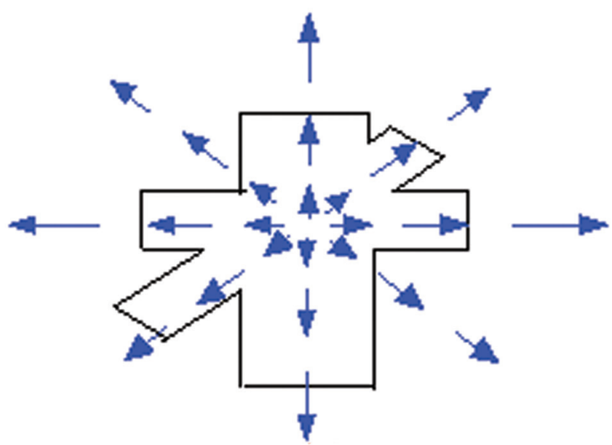

Figure 2 : flow field for a vertical landing.

Figures 1 and *Figure 2* are essentially the same as the ones used by Gibson by to clarify his idea.[2] They give a pilot's-eye view of both a normal and a vertical approach to a landing strip. Except for the characteristic shape of the runways, both figures could relate to any scene where any surface is being approached in the same manner. Thus, for example, it would take little to adapt *Figure 1* to represent the flow of information received by the driver of a car proceeding along a road and *Figure 2* could perfectly well represent a head on approach to a vertical wall. Thus, in the illustrations, the shape of the runway is only useful in making the idea more vivid: it would not help the pilot to judge the critical relation between aircraft and runway. The only necessary information is provided by the patterns of change in the surface-texture, namely the *flow-fields*.

Once locked into the idea that whenever eyes are moving through their environment, similar layouts will generate analogous flow-fields, Gibson was on a roll. He considered *movements of the whole person through the environment*, of the *head relative to the shoulders*, of the *eyes rotating in the eye sockets* and, even, changes in the *shape of the eye's inner lens*. Always, his question was, "*Are there any invariant transformations generated by these movements*?". Over and over again, he and his growing band of followers found that the answer was "*Yes*". Of particular interest to them were ways in which movement created invariant:

- Transformations of *surface-texture* and *shape.*
- Relativities of movement between near and far objects ("*motion parallax*").
- Obscuring and revealing of nearer and farther objects. ("*overlap*").

In general, it was abundantly clear that a *dynamic visual system is afforded a great deal of information by its environment*.

All these ideas were to stimulate fruitful experiments. One of the outcomes of these was the general recognition of viewer-movement and object-movement as two of the most powerful sources of visual information in everyday life.

A limitation to Gibson's thought

Gibson had a very combative personality. He launched scathing attacks on the traditionalists within his field and, not surprisingly found himself subject to much counter criticism. One of the main reasons he was derided was his insistence on the irrelevance what goes on inside the head. His attitude signified more

2 Gibson, J.J., 1950, Perception of the Visual World, Houghton Mifflin, Boston

than a mere lack of interest, it amounted to an obsessive antipathy. He poured scorn on researchers who sought answers by studying the internal machinery of eye and brain. For him anything that happened after the light array arrived at the retina was a distraction and an irrelevance. Research into the structure and properties of neural systems a total waste of time.

A question arises

Since this book spends so much time explaining ways in which a study of eye/brain systems can advance understanding, the question which arises as to what degree Gibson's insistence on keeping outside the head, limited his achievement. While it cannot be denied that a refusal to consider something reduces the scope of an enquiry, this is by no means the same as saying it is a bad thing. Though restriction necessarily restricts, it also invariably focuses attention in a particular direction. Any scientist who makes use of experimental controls of any kind is implicitly recognising this. In Gibson's restrictions had the advantage of confining his research to questions and hypotheses that nobody else had seriously considered, thereby opening up new and fruitful domains of enquiry.

At the same time, Gibson's challenge to the methods and conclusions of his opponents, put them under pressure to justify what they were doing. Whether right or wrong, Gibson had a galvanizing effect on the study of psychology of perception.

Inside the head

What might have happened if Gibson had looked inside the head? We can only speculate, but here is one idea. As everyone knows, surfaces that are being passed by at speed appear blurred. But why is this so? The explanation depends on the fact that the receptors in the eyes take time to pick up and process information. In this respect they operate like cameras. Thus, if someone were to drive fast down a long straight road and take a photograph, through the front windscreen, of the road-surface as close as possible to the front of the car, the resulting image will be blurred. The reason is that the texture information coming from the near-distance road-surface will be changing so rapidly that different parts of it will be represented on the same part of the film. Effectively, there will be a multiple exposure. In contrast, the road in the far-distance changes much more slowly and an clean cut image can be produced with a relatively slow film/shutter speed.

The relation between car-speed and blur means that a camera can be used to measure either the speed of the car or the distance of a given patch of road. Thus:

- If a photograph is taken by a camera using a fixed shutter speed, aimed at a fixed distance in front of the car, at a road of uniform surface-texture, the blur profile in it will vary in direct relation to the speed of the car at the moment of exposure.
- Likewise, if a car is driven at a constant speed and the camera, using a fixed shutter speed, is panned up and down so as to focus on nearer or further parts of the road, then the amount of blur will vary in a predictable way according to the distance from the camera of the part being photographed.

It follows that, if the visual system, like the camera, takes a fixed time to integrate information arriving at the retina, it too should be able use blur as measure of either speed or distance. And we know it does from studies of the phenomenon of the greying-out during saccadic eye-movements.[3] In this case, the speed of the swivel of the eye-ball is so rapid that the information arriving at the retina cannot be gathered fast enough to inform the eye/brain of anything except the average level of illumination.

With these ideas in mind, imagine someone walking at a steady pace towards the wall of a house, starting several hundred yards away from it. As is well known, the apparent size of the wall will increase. At first, the expansion rate will be virtually imperceptible. However, it will progressively accelerate until, immediately before the moment of impact, it will be expanding very fast indeed. Nor is the pattern of expansion uniform, being slower at the centre of the visual field and faster at the periphery. Indeed, no matter how fast the approach, there will be a point of zero expansion at the very centre. Thus, assuming, for the sake of argument that all the receptive-fields in the retina have the same structure and size, this would mean that the blurring-out of the wall's surface-texture would occur first at the periphery, next adjacent to the periphery and so on in a series of ever diminishing concentric circles, until the centre is reached. It follows that, given that the rate of approach is known, the extent of area of the retina not blurred-out provides a measure of distance from the surface.

Now assume that there are receptive fields of different sizes. The time taken to blur out will be proportional to their extent. From this it follows the greater the

3 Campbell, F. W. and Wurtz, R. E. M., 1978, Saccadic omission: why we do not see greying out during saccadic eye movement. Vision Research: Vol. 18 pp. 1297-1303

range of receptive-field sizes, the more different "*blur-profiles*" will be provided and, consequently, the more information about approach speeds. Furthermore, the existence of the larger field-sizes will ensure that complete blurring out will seldom occur. An exception would be the moment before a speeding car crashes into the brick wall. At some juncture, very close to that moment, the expansion rate would too fast for integration even by the largest receptive fields. Accordingly the driver would become functionally blind.

The above description is no more than the basis for a speculation. However an hypothesis based upon it will have a high level of *neurophysiological plausibility*, since the retina has the required range of *receptive-field sizes* and therefore, will certainly make available the relevant distance and speed data in an easily interpretable form. In view of the lack of plausible alternatives, it seems hardly credible that the evolving brain would not have learnt to make use of this extremely valuable source of information. Also, when we get to explain the *colour constancy algorithm* proposed in *Chapter 11*, we will see that analogous logic, based on the use of different size receptive-fields, can enable the extraction of invariants that tell, not only of *body colour* but also of *ambient illumination, surface-form* and in *3D spatial separation*.

Bernstein and footbridges

The purpose of including a short detour via the work of the Russian mathematician Nicholas Bernstein is to provide a link between Gibson and Johansson. Some twenty years before Gibson was confronted with the mystery of the crashing pilots, Bernstein was faced with the problem of designing the footbridges for railway stations in post-revolutionary Russia. Wanting to find the best possible solution, he decided that he should start with the basics and set himself to study the way people walk up steps and inclines.

The first stage of any investigation must be the gathering of data and this means both deciding what information is needed and working out how to collect it. Bernstein needed to find out about walking movements and he hit upon the idea of strapping rows of lights along the length of experimental subjects legs, such that they bridged the articulating joints (the ankle, the knee and the hip). Rigged up in this way, the subjects were instructed to walk up or down gentle slopes, while a photographic record was made of the changing relationships between the lights as produced by their actions.

Being a mathematician, Bernstein's goal was to was to provide a mathematical description. Basically, this means that all the main features of the thing being described have to be accounted for and placed in meaningful relationships. To achieve this end, each independent variable has to be isolated and given a separate symbol, which can then be placed in a mathematical formula. Bernstein found that he needed information concerning the:

- Mechanical properties of legs (described as a set of jointed levers)
- Ongoing adjustments to the profile of the ground being walked over.

There is no need to go too deeply into his arguments, but the only way he could find of explaining the *"ongoing adjustments"* required him to include symbols for both *bottom-up* and *top-down influences.* What his mathematics revealed was that the brain must correlate input from three separate sensor-systems and the use the results to adjust actions action-instructions that would take account of the characteristics of the ground being walked upon. The three systems derive their input from:

1. Touch-sensitive sensors in the feet,
2. Movement-sensitive sensors in the articulating joints and
3. Light-sensitive sensors in the eyes.

Bernstein's formulations were extremely elegant and well ahead of their time. Their value as a demonstration of the interdependence of bottom-up and top-down processes in the operation of a visually guided skill is self-evident. They also suggest that there are invariants in the movements of joints that could in principle give useful information to the eye-brain in its quest to make sense of the visual world.

Johansson's demonstration

As a result of the political isolation of post revolutionary Russia, Bernstein's work was not made available to the rest of Europe until 1967, when a translation of various of his writings (including his footbridge paper) was published.[4] Amongst the many people who were to be influenced by his ideas was the Swedish researcher Gunnar Johansson. In effect, what Johansson did was to fuse ideas coming from Bernstein with ones derived from Gibson. One of the spin-offs from his achievement was a surprising and powerful demonstration that halts in his or

4 Bernstein N.A., 1967, The Coordination and Regulation of Movement, Moscow

her tracks anyone who believes they have a comprehensive understanding of visual perception. This shows that the human visual-system can pick up a great deal of information from patterns of movement that takes no account of contours. The reason it has been so influential is both that it drives a coach and horses through any hypothesis that gives priority to making sense on the basis of contours, and that it brooks no denial. Nobody who has seen Johansson's demonstration can ever again suppose that vision is a simple process, involving a straightforward translation of an image to the mind's eye. Nor can anybody ever again deny that the recognition of objects can take place in the absence of colour, surface-form, surface-texture, or contour derived information.

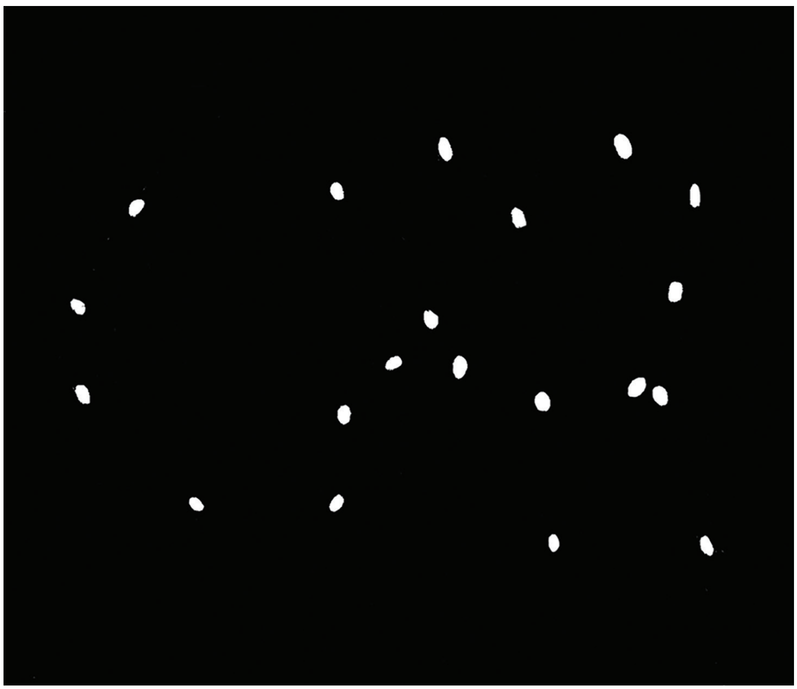

Figure 3 : Johansson's lights

My knowledge of this demonstration came from personal experience. I was sitting in darkened room watching the opening sequence of a film about the work of Johansson. On the screen appeared twenty-four stationary points of light analogous to those illustrated in *Figure 3*. What happened next was astonishing to everyone. The dots began to move and, as they did so, seemingly instantaneously, they took the form of two people. One of them bent down, picked up an invisible ball and threw it to the other, who caught it. The perception was unambiguous and vivid for everyone. In my own case, I found myself imagining clearly delineated outlines around the figures. If these had really been visible, the film would not have been very interesting. But, they were not. My brain had constructed an illusory perception from the dynamic relationships between the moving points of light. It was another kind of blind-sight, but this time perceiving outlines that was not there.

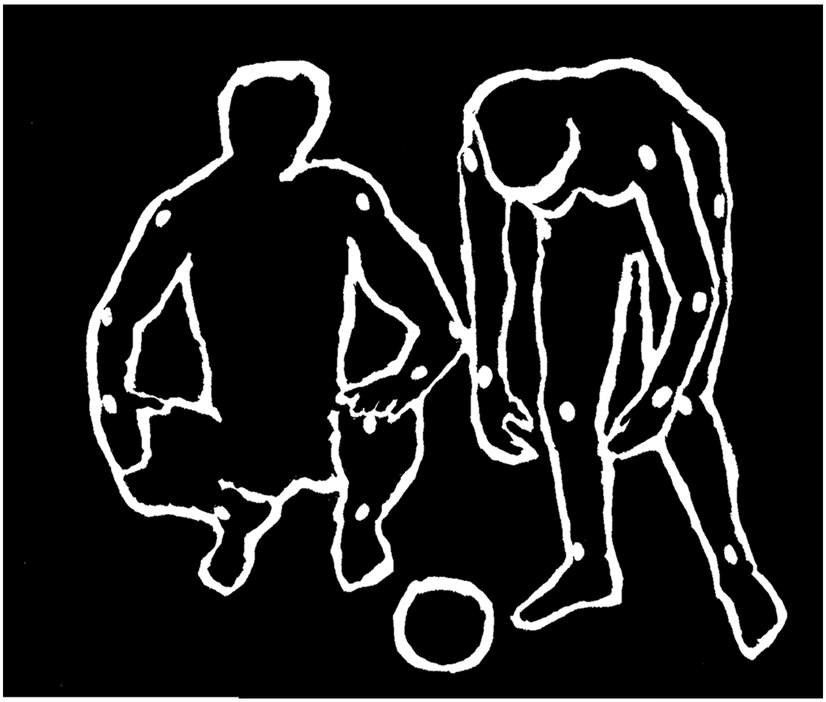

Figure 4 : Johansson's lights explained

How had this seeming miracle been performed? It turned out that, inspired by Bernstein's proof of the power of mathematics to deduce information derived from lights attached to articulating joints, Johansson had been persuaded that the eye/brain systems could make analogous computations. To test this idea, he attached small highly reflective discs to the main articulating joints of two actors wearing dark suits. He then situated them in front of a dark background and shone a spotlight on them. At their feet he placed a ball, approximately the size of a football. A film was then made. First the actors were asked to stand still while the static display of light sources was filmed. Since the actors in their black suits against the black background were invisible and since the reflective patches were far-and-away the brightest elements in the scene, when the filmed image was displayed on the screen, all that could be seen was an array of isolated bright spots. The actors were now asked to pick up, throw and catch the ball. As they did so the reflective patches began to move in coordination with the movements of the actors. Immediately and quite unexpectedly, the dots came alive and took on the appearance of two human being playing with a ball. *Figure 4* gives an idea of how the dots could relate to the figures at the moment when one of them was leaning down to pick up the ball.

Obviously, similar arrays of discs could be attached to other actors doing different things, allowing many variations on the Johansson demonstration. For example, Richard Walk, another investigator, used Johansson's method on actors who were instructed to act out different emotions (sadness, happiness, fear, surprise, anger and contempt). Spectators turned out to be very good at identifying the simulated moods correctly. Indeed, they performed as well as the people given the task of identifying emotions from facial expressions in photographs.[5]

Even though Johansson's demonstration involves a very artificial visual world, it is inconceivable that the powerful interpretive system it reveals remains unused in everyday life. On the contrary, it must surely be used a very great deal.

What, then, are the sources of the information that enable these miracles of perceptual construction? There can only be three:

- Direction of movement.
- Expansion and contraction, with variations in distance from the viewer.
- Appearance and disappearance, due to overlap.

Obviously, none of these sources can be of any direct use to anyone attempting to depict a static image.

Implications

This chapter has focused on movement as a source of information. Gibson's

5 Walk, R., D., 1984, 'Event perception, perceptual organisation and emotion' In: Cognitive Processes in the Perception of Art, Eds. Crozier, W.R. and Chapman, J.A., North-Holland, Amsterdam

idea is that our visual systems somehow recognise the spatial layout of surfaces by means of what he calls flow fields.

Bernstein showed that invariant relationships between shining discs tied to the articulating joints of the human body in motion can be described mathematically in terms of a small number of variables. The Johansson's demonstrated difficult to avoid the conclusion that Bernstein's formula forms the basis of eye/brain computations that accomplish this seeming miracle.

Johansson's demonstration relates to the unilateral neglect studies described in the last chapter because both are concerned with the ability of the eye-brain to imagine (that is to say, create consciously describable images) on the basis of existing knowledge. Johansson goes beyond Bisiach and Luzzatti by showing that people can imagine complex outlines that do not exist. The moving discs of light provide sufficient information to tell, not only that they are looking a two moving figures but also what they are doing. The outlines that I and others were amazed to find ourselves seeing can only have been put in by referring to an already existing knowledge-base.

In summary, this chapter has added demonstrations of the importance of movement in visual perception to the insights coming from the study blind-sight and unilateral neglect found in the previous one. Both chapters have also paved the way for providing explanations as to how all these phenomena might result from computations made by eye/brain structures using complex neural pathways. However, going deeper into this subject will have to wait for the chapters on more general theory (Chapters 15 - 21). Meanwhile, there is more relevant experimental evidence to add.