TODAY'S NEUROSCIENCE, TOMORROW'S HISTORY

A Video Archive Project

Professor Richard Gregory

Interviewed by Richard Thomas

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Interview Transcript

Early years and influences

I was brought up in London where my father had his observatory. He was an astronomer and he was the first director of the University of London Observatory, which was, and still is in fact, in Mill Hill, and was being built when I was quite small.

There were three telescopes in the observatory, and the smaller one I actually used a lot. We sort of called it 'my telescope' and it was quite small. It was an 8-inch refractor, and I used to look at globular clusters and stuff like that, and I had my own spectroscope and I had a little laboratory with instruments. I always loved playing about with them. Luckily, the kind of play wasn't serious science. I used to sort of play with instruments and look through telescopes without really doing much in the way of making proper measurements, that sort of fooling about, which I must admit I still do to some extent.

Then I went up to Cambridge. I got a scholarship from the Air Force actually, and I went to my father's college, Downing, in 1947 to read philosophy and also experimental psychology in my third year, but started off really in philosophy. And I met wonderful people like Bertrand Russell. I saw him every Thursday afternoon for a year, actually, Bertrand Russell, which was great, talking to him. Bertrand Russell was very, very keen on probability. On arguments not deductively but inductively from instances/examples, and that got me interested in that, really from Russell. And then I started to think the brain works like that; the brain is building up inductive generalisations, and that that really is the nature of intuitive knowledge. From really, very much from Russell's ideas.

Cambridge 1947-1967 – Doing what I liked at the Applied Psychology Unit

Well, I graduated in 1950 and my first job was at the APU, the Applied Psychology Unit, which was in a wonderful country house just outside Cambridge, and it was a fantastic laboratory where people did practical problems given to them by the Government or by industry, and then you had a lot of time where you could work out your own ideas. So in that way, it was a bit like MIT, not very much, well, MIT yes, but also the Bell Laboratories in America, where you had time to think and you also had directed research and I think that combination is actually wonderful.

You know, I was actually amazingly lucky for various reasons, one of which was, we got a new wing to the building. It wasn't a complete new building but it was a wing added on and I was given the whole of the top floor for my own laboratory, and Larry Weizkrantz, who became professor of psychology at Oxford, had the same. He had the floor below mine. I mean, it was physically below mine, I'm not saying it was intellectually below mine. And he had his monkeys on his floor, and I had my vision and hearing stuff. I had a soundproof room also for hearing and I did my experiments on space for the moon landing there on that top floor, and had my students there. So I had my own little empire. I was only a lecturer at that time. I wasn't a reader or professor – just a lecturer, but I did have my own empire, little empire, mini empire. You know, to do what I liked, and it was really an amazing thing. I was financed by the Medical Research Council and basically I could do what I liked. I had my own workshop, my own dark room, laboratories, some very, very good students, who many are still friends, you know, and it was just a sort of wonderful thing. But there's luck in life, isn't there? I just had a very good hand dealt to me by chance at that time.

Behaviourism: a maze of dead ends

In my teaching I tried to steer my students away from what I thought were dead ends and in fact I steered them away from behaviourism. In particular I steered them away from mathematical models of learning. At that time there were a lot of people developing elaborate mathematical models, you know, for learning, that is, you put a rat in a maze and you get gradual learning. You get different things happening and I just felt this is too complicated to express in a reasonably simple equation. It just wasn't going to work and I think a lot of my students were actually grateful to me, they've said that to me. Simply forget it, it's not going to get anywhere and it didn't. I was absolutely right about that, I think. Now behaviourism again was throwing out a very interesting baby with tepid bathwater because what I think what is interesting, how the brain assesses information to make judgements, to make predictions, to be active, in my view to develop hypotheses of the external world and act on those, and where consciousness comes in. And all that is completely different from behaviourism which was a kind of passive view that you get stimuli impinging on the nervous system. You respond to these stimuli rather like a billiard ball responding to being clonked with a cue, and in principle you can predict what's going to happen. I thought it was completely different from that.

Perception: inspired by the man who was born blind

Well, the sort of turning point really in my sort of thinking about perception, indeed initiated my interest in perception, was studying a man who was born blind (I'll go into that in case we need to qualify, in a minute) and then got his sight back when he was fifty-two, by operation. And he was called Sydney Bradford. We always called him 'SB' and this was really the turning point. What happened if you suddenly got sight from no sight over years? And this is discussed by John Locke, originally suggested in a letter from Molyneaux who was an Irish friend. What would happen if, you know. Well, here was a case. It really did happen. This chap was effectively blind from birth and then got his sight back so this is terribly exciting. How did I get on to that? I got on to that through my research assistant, who was called Jean Wallace. Very, very nice lady. We worked for years together and she read in her local newspaper – she lived somewhere near Birmingham, I believe – that this operation was about to happen. It was before the operation so she showed me this little note in her local newspaper and we decided to jolly well go and have a look.

So we were there at the time of the operation and we studied him as soon as we could after the operation, probably about one day; certainly not more after the operation. And we found a middle-aged, very sensible sort of chap, who was walking around, apparently using his eyes. He apparently guided himself through doorways by looking, you know, and we did a lot of tests on him, and he was very cooperative.

I borrowed an alarm clock from a nurse, turned the hands around to different times and I found he could read the time with his eyes, although he'd been blind for fifty-two years. And what on earth was going on? And he then produced from his upper pocket in his jacket a big watch, which opened. It was a Hunter and he flipped it open. It had no glass in it, you could feel the hands. He put his fingers on the hands, moved like that, and told us the time immediately by touch from his watch. And it turned out that he could use touch knowledge from when he'd been blind to seeing things such as telling the time. More than that, he could actually read upper case letters, that is capital letters. They'd been taught to the kids in the blind school as they were engraved on wooden blocks and the children were made to run their fingers around the grooves in the blocks showing the letters. And they could read letters in brass plates and that sort of thing by touch. Enough letters apparently for that but only upper case letters – this is crucial.

I was wearing a raincoat, for some reason, in the ward – I don't know why but I was – and it had a magazine in the pocket, which was *Everybody's*, which at that time was a very well known magazine. And he looked at it, didn't feel or touch it of course, looked at it, and said, "Is that *Everybody's*"? Now I was flabbergasted, but let's analyse what happened. First of all, he knew the name *Everybody's,* and *Everybody's* was a magazine, from talking to people. He had a lot of knowledge in his head. It then turned out that he could read the letters just showing above my pocket, which was an E and a V, particularly, which were in upper case.

The knowledge he had as a child, childish experience, transferred to vision at the operation. It was already available to him and was available to him after he'd been operated on because it transferred from touch to vision. And I think this is the first example of clear evidence of transfer from touch to vision.

We showed him a whole load of illusions. We showed them, though, because I simply used what I used for my students in practical classes because it was the thing that was to hand. I filled up my car with these different things and we tried them out, you know, because anything went. I mean, we had only a day or something to prepare these things, you see, and we found that his illusions, that is his distortions, were minimal. I think they were there a little bit, but minimal, and that made me realise that it couldn't be a physiological difference, it must be a cognitive difference, it must be experience or knowledge of the shapes, you know, which were important, and so I very soon got the view that these illusions are really cognitive phenomena, not just physiological phenomena of the signals being disturbed in the eye or something.

The Necker cube and other illusions

Well, what is this? It's a drawing of a cube but the faces are all the same size, particularly the nearer and the further one. But which is the nearer and which is the further? As you go on looking at it, it will suddenly change, it will suddenly flip. What did appear to you as the nearer, suddenly shoots back and becomes the further, and it keeps on doing that. It alternates: near, far, near, far. And this is the flipping of the Necker cube.

The brain can't always make up its mind. I like these phenomena very much and you get what I call flipping from one perception to another, which *is* entertaining or trying out one hypothesis and then another. You change the hypothesis.

Well, we see here three circles or disks with bits missing. I think of these as cakes, like black cakes with slices taken out. But lo and behold, you see something else, which is not really there. You see a white triangle joining up the slices. That is a ghost. It is purely illusory and the edges that you see are not there. There is no physical edge whatsoever and blow me down, what the brain does, it says, “No, they’re not slices at all – they’re being hidden from real cake by something in front”, which is a triangle, which does not exist. So you’re seeing something that the brain cooks up to explain the slices in the cakes.

Eye and Brain, 1st edition 1966; 6th edition 1998

I really enjoyed writing it very much. I felt I was sort of trying to communicate things that to me were important. I tried to write it not as a textbook but, at the same time, I wanted it to be useful for students, although not the textbook, and it’s a tricky thing to do. I think very well worthwhile actually, and I don’t mind, you know, if a science book has some jokes in it. I think its okay, as long as it gets the idea over. So I got this book out in really quite an austere period of time, not very long after the war, lavishly illustrated, which, for a book on visual perception, is pretty important, you know, and that’s sort of how it happened. And then I enjoy the process of writing: having a conversation with oneself, and realising in the middle of the night one has been a complete idiot about something, you know? It’ just the same as somebody else calling you an idiot. You sort of shudder. You think, “Oh how could I have been so dense?” Exactly the same sort of thing, but to my mind this discussion with yourself when you’re writing is really what makes one a creative person, if that’s possible to be. And it stops one being too arrogant, taking oneself too seriously because oneself is criticising oneself, and one, a little bit of oneself might be quite pleased but on balance you realise it’s never going to be that amazing. But at the same time you keep going because of the fun of the conversation in your own head. This is sort of what’s happening, I think.

Edinburgh 1967–1970 – the birth of artificial intelligence

There was something about the situation between physiology and psychology, which took me away from Cambridge, which was really this: the physiologists at that time were not really interested in the brain. It was too difficult to do empirical work on the brain. There was a lot on the eye, on the ear, on conduction in nerves, which of course Lord Adrian, I mean, was the great person who discovered how it all worked. I mean, what they did was fantastic. I’m not criticising it one bit, but I was interested in the cortex, in the brain, and the creativity of the brain, and so on, which at that time was completely beyond the possibilities of physiology.

Horace Barlow is still a friend. He's actually older than me, amazingly, but he's still active in Cambridge, doing research. He's got a fellowship, interacts with students; he's a wonderful man – full of ideas. His ideas are as fresh now as they were then and he's in his middle to late eighties, you know, he's getting on. He's just the sort of academic one should be. Well, I suppose I felt in a way they did their thing better than I would ever do it and I did something a bit differently, so I never got into nitty gritty physiology, basically. I got more interested in how the brain works cognitively; what sort of mental processes go on, rather than the components and how they function, which makes the brain work the way it does. I was more interested in its strategies than the details of the physiology.

Now, artificial intelligence came along. Naively, I thought we could do experiments -- if you like thought experiments -- but also experimental, using computers, and that we could programme computers to be intelligent; to see things; to make decisions. And by doing that, we would discover how the brain worked because it was too difficult to do it directly with physiology. So I was one of the three people who started the first department in Europe actually of artificial intelligence, in Edinburgh, and that was really the reason that I got impatient with the restraints or restrictions of physiology, basically, and that was the point. And I think also when I was at Cambridge, the physiologists had a higher social standing than we did in psychology and one always felt one was being sort of pecked on the top of the head by superior birds, if you like, in the physiology department. And I got a bit fed up with that too, so I thought, hell, let's start something new, another approach, you see, which was fairly naïve really. And so I gave up my fellowship -- free port every evening and all the rest of it -- my wonderful students, my wonderful laboratory, which was superb, to start a completely new subject with people I hardly knew in a city that I didn't know, which was freezing cold. It was a pretty silly decision in many ways, I have to say.

It wasn't really the weather, it was the fact that the computers were absolutely not up to it, and we were not up to the computers. We just didn't know enough about computing. That was the problem. So, what we did wasn't in a way a waste of time, it moved things along. We founded a department, which is still important now, and we had absolutely wonderful people working with us. The students and our colleagues were really top-notch people and it helped to get them going, so a number of good careers were formed from that. So I wouldn't say it was a complete waste of time at all, though I myself did not benefit from it.

Bristol University 1970 - -- science for kids and the Bristol Exploratory

I chose Bristol because it had space in the anatomy department, and I knew the professor of anatomy, a friend of mine, and I thought I could move here relatively easily without having to build a new building and all that stuff, you know. We had all these problems in Edinburgh actually. And I could get going pretty fast. It was near London and it was sort of convenient. Also I didn't know it. It was fun to go to a place one actually didn't know and I don't regret the choice. I've always liked Bristol. They've been very good to me and I had a very nice laboratory here; got a lot of interesting things done. It worked out actually very well.

I thought it would be really great to have a science centre where kids could be quite free to do their own experiments and their parents perhaps helping them. Both children and parents. And this is not altogether an original idea. It goes, in a way, back to Bacon in the 17th century, and Frank Oppenheimer who started the Exploratorium in San Francisco, just after the war. And this is exactly what goes on in the Exploratorium. So my humble sort of end of this was to start something like the Exploratorium in Bristol. We call it the Exploratory, in deference to Frank, and we had about two million people come round it. Two million children mainly, and it was in the old railway station at Temple Mead. It had other locations actually as well but mainly there and it really was a tremendous lot of fun. And I'd really like to say that the first exhibition we did was supported and paid for by David Sainsbury who is one of my hero figures. He was also my student. I supervised David Sainsbury when he was at Cambridge, when I was a lecturer and he's been very, very generous in supporting my work and lots of other people's work. Amazing man.

I would like to see science centres everywhere interacting with people, interacting with schools; that are helpful to schools, not antagonistic to schools, and it means that schoolteachers could develop their ideas. They could interact with the children in a richer, more interesting way, not dominating or limited by curricula or anything like that.

Perceptions – Dalmation dogs and the image in the eye

This is an actual photograph. I'll tell you what it is and then you might see it. It's actually a Dalmatian dog, and a lot of it you can't really see but once you realise or see it as a Dalmatian dog, then the rest of it kind of fits in and you can extract the dog from the pebbles on the beach. Perception is solving puzzles. Whenever we see any object, we have to separate it from the background. You have to see it as a thing in its own right. Here, because it's difficult, you can see your own brain at work. There are all sorts of lessons about perceptions in this Dalmatian dog.

The major discovery in vision, is the image in the eye. The fact that you've got a little picture in the eye and that you've got the external world out there. You've then got the picture in the eye, then you've got the brain which tries to read what the reality is from the picture in the eye, and it's important to note that you don't see the picture. The picture is a stage, if you like, from the object to your brain, but you don't have an eye looking at the picture in your eye. It simply is providing information to the brain but the really important point from all this is that the perception generated in your brain is very distinct from -- it's separate from -- the world out there because of this image thing. Images between the object out there and your experience. Ditto with a television camera feeding into a computer. That separates the computer from the external world. The computer or the brain has to guess what is out there on the basis of information from the image, and it's not direct.

Perceptions – where are colours?

Are colours in objects? If we look at a … take a modern object, you know, a pillar box, and the experience of the red in the pillar box we now call 'qualae' (sensation). What is that relation? Is the red really in the pillar-box? And that was a question that Locke and Newton were both concerned with, both wrote about, and they both came to the view that the colour is not in the object, it's in the eye, it's in the brain, but not in the object out there. And as soon as you said that, of course, it means that perception cannot be direct, but all that started, as far as I can understand it, from Locke and Newton, who argued about this, you know, and set up a debate that still continues. Of course the question now is what is actually out there? Is heaviness out there, is squareness out there, is a straight line actually straight out there, or not? Or is colour on its own? Is it something different? Locke talked about primary and secondary characteristics and this is still a very, very difficult issue. What is primary (actually out there), what is secondary (created by the brain)? And this is still a matter, I think, of debate.

Perceptions – signal to noise ratio

Any detecting system, such as a radar receiver or your domestic radio or television, all this is a question of separating the signal from the noise. The signal always has some randomness to it, which you might call it static in the old days, or flashes on the screen of your television set, and it's always there. And sooner or later you have to make a decision as to which change of electrical activity is random or genuine signal, and this decision has to be made either by a computer, which it can be done, or by the brain. And the signal to noise ratio, as it's called, is critically important.

I don't think that Helmholtz thought much about noise actually. I think that was a rather later idea but he was very well aware that a given retinal image could represent umpteen different kinds of objects. He was completely aware of that and he actually talked about looking at a room in dusk without too much light around the place, and it might be a square room or it might be a funny shaped room, giving the same image in the eye. In other words, he knew about ambiguity, and it was *that* that I think he was concerned about. That you make a guess or an inference as to the shape of the room from knowledge of rooms and from rules such as perspective and so on, and that that is how in modern, rather nasty, terminology, you disambiguate the image, that is, you settle for one bet as to what is actually out there from an image that might represent umpteen different kinds of objects. It might be big, it might be small, it might be parallel, it might be converging lines, sort of thing, and he had that idea. And his idea was that you infer from rule and from knowledge of objects but this is actually a sort of inductive influence. It's not solid deductive influence. It involves a lot of guessing, you know, in terms of probabilities of the kinds of shapes a room is likely to be, for example.

Perceptions – the creative nature of perception

Well, lets look at a rectangular object. Not a room. This is simpler than a room. It's simply a dinner mat and it's actually a rectangle. I'm holding it at right angles to the camera now, but now what happens if I tilt the thing so that the top of it is going further away. Now two things are happening: physically in the camera or in your eye, the top of it, which has got further away, has got smaller than the nearer part at the bottom but you're seeing it not changing the size of the mat. The mat isn't changing and expanding. Its jolly well tilting such that you're perceiving the smaller image as a more distant object or part of an object, and this is an 'inference' in Hemlholtz's term. You assume that the mat remains the same shape but you see it as tilting. If the mat could change its shape then it would not be a valid inference to say that it's tilting so it's all based on assumptions, and Helmholtz recognised the importance of assumptions for seeing.

I think one *can* make a distinction between Helmholtz's 'unconscious inference' and perceptions as hypotheses. The difference really I think is this: that the hypothesis is like hypotheses of physics, of science, and it's really extrapolating from known evidence to make a guess, which might be a leap or jump to what could be a richer truth than available. And this jump from probable data and to a rounded story of what's going on, is the hypothesis, and that involves, I think, the bigger sort of creative leap than the idea of unconscious inference. So I would think it emphasises the dynamic nature of perception, the creative nature of perception. That you go from limited data to an amazingly rich experience of the world, which is the point, and that is what I think is captured by the idea of hypotheses plus the importance of prediction, that hypotheses predict future and they predict what is missing in the information around you. They fill in gaps and all that is important in perception. So I prefer the idea of 'perceptual hypotheses' to Helmholtz's term 'unconscious inference'. I think you need that extra richness to cover perception. I think perception is a hypothesis. That's exactly what I think. It is a hypothesis. It's a bunch of guesses.

Size Scaling – perspective and the Ponzo illusion

Well, what is quite a complicated business is this: you've got an image in the eye, which is perfectly straightforward, dead simple optics. It's simply, it is a point out there in external space is registered on a little region of the negative in the camera or the image in the eye. So if you've got a point out there, it goes through the eye and then it gets to the given bit of the retina, so you get a pattern on the retina or a camera corresponding to where objects or parts of objects are in the external world. That's easy but, of course, objects are at different distances so what the brain has to do, *and* when you're looking at a photograph, is to judge where the objects are. And when they get further away or are further away, they get smaller by optics but that might be that they're further away or they're *actually* smaller, so there's always a judgement that needs to be made. Now, there's a process in perception itself, which to some degree compensates for the shrinking of the images with distance, and this is called size scaling. And I'll pick up an object, if I may. Lets start with this. This is actually rectangular. It's at right angles to you. Now, if I move this further away or nearer, it changes size in the camera and in your eye. Is that enough to see the difference? It should be, yeah. Now, you can either see this thing shrinking and expanding, which it might be, or as not actually changing its size but changing its distance, and here probabilities come in. If it's unlikely to be changing its size, if it's a tablemat or the head of your friend, much more likely that you're changing distance and that's what you see. But you can play party games on this. Imagine that you've got a balloon, and let's say to make it extreme, that you have it luminous in the dark. You then make it get bigger or smaller, blow it up or let it down. You see it as getting bigger or smaller but actually its changing size. Or take a cartoon film. You represent something getting further away or nearer by changing size on the screen in the cinema and you normally see it as going in and out in depth because, and simply because, it's jolly unlikely that its changing size. People's heads don't change size. Even tablemats don't change size. Now it happens that balloons can change size: they're unusual objects. So what happens is that the brain makes a decision unconsciously about whether it's changing size or whether it's changing distance, and the probability sets what happens pretty well. But in addition to that, or related perhaps to that, you've also got compensation going on, that when you've got a change of signal distance or size, the brain can compensate.

This is called Ponzo illusion. If we look at a photograph of a scene in perspective like railway lines, the two white rectangles stuck on the photograph are actually the same size but the upper one, similarly to the original Ponzo figure, will look a bit bigger. Now, we see here that it's really further away by perspective. Size constancy operates, which expands further objects as they are shrunk in the eye, and that compensates for this optical shrinking. So what we're seeing here is what is usually a useful correction, sort of shrinking of pictures in the eye. Here, on a flat picture, it produces a distortion. The compensation is not appropriate to a picture plane, to a flat plane, though it is to the real world, and so what is normally useful -- helps you to see things correctly -- here produces a distortion, as it's a picture.

Size Scaling – the moon landing and the honorary colonel

Well, rather amazingly, I was actually asked by the American Air force -- this was just before NASA actually -- just before, to work on the moon landing, which of course occurred in 1969. So this would have been in the sort of mid-sixties, a little bit later than that, and as the laboratory was being built in the new wing of the building, I had the opportunity of building a simple space simulator into the laboratory, into the building you see. And so we made a sort of electric railway which ran right along the building basically, and through my laboratory, with a little carriage on it, which you could sit on and you were carried along. And then I had visual displays which changed their size as the carriage drew you towards or away from it. In other words, if you were drawn nearer to it, the display would shrink, and as you were moved further back from it, it expanded. And one of the tricks was to make it apparently the same size as it looked as you went nearer or further from it, and that amount that it had to change was a measure of what we call size constancy: constancy scaling. And it had a vague sort of relevance you know, to space travel, particularly docking. How do you dock in space? Now the problem with docking is there's so little information available. You've got the black void of space, you've got a few specks of stars at infinity. You don't have perspective, you don't have things getting dimmer or more blurred with distance as you get on earth. In other words, the visual cues as we say, or clues, were absent as in space, and so we had to predict what would happen to astronauts when they were docking or landing on the moon from experiments like this, which is what I was trying to do. At the same time, I was trying to learn about vision; about how it worked normally in these situations because I could control them. So it was a two-edged sword, you see, which was great fun. So it was a bit of 'Boys' Own' stuff: space, going to the moon and all that sort of stuff. At the same time, it actually had some science to it. It was also very good for visitors. They used to love riding on this thing. Great fun, so it combined everything.

They made me a colonel actually. I was an honorary colonel in America. I didn't have a uniform but I had a piece of paper saying I was a colonel. Quite honestly I waved this about – it was incredible. I could get onto an aeroplane that was full, I could travel for nothing anywhere, stay in any mess in the States, navy or the army or anything, you know, for free. Being a colonel: incredible!

Parallel Processing – eye and brain convergence

Well, if we look at any object, especially one we know something about from past experience, and I'm going to take this mug or cup here, and I'm going to pick it up. And I predict first of all that I'll be able to pick it up and when I move it like that, it will change its shape to you. In other words, this will become more like a circle and that will be an ellipse when it's tilted. It goes through transformations, but my brain tells me that this is not actually changing shape, that it's remaining truly circular, although it's elliptical there in your or my eye. That's the first point. So the hypothesis is from changing images in the eye to an object, which is not changing. It may be tilting, it may be getting nearer or further away and so on but its actual shape is remaining fixed, although it's not fixed in the eye. That's the first point. So the hypothesis takes from the changing retinal image to an object, which goes on having a circular top; its parallel lines here, and it's got a pattern on it, which in a way is painted on it. It's separate, in a way' different from the cup itself. It's seen as a picture and that's an interesting distinction. What is an object, what is a picture? All that comes out in this thing. Now, again when it's moving, you find that the different parts of it all move together and this is actually very surprising because the eye signals these different characteristics: shape, colour, movement, in parallel different channels and yet to the brain it's all moving together, though the signals from the bright bits, that is the white bits, are going to arrive at the brain sooner than from the dark bits, such as these parts here in the picture on the cup. Although these differences in time should mean that the thing dislocates parts moving faster than others, it all looks like one object moving. So they've locked together through locking processes, which -- we call them 'border locking' -- which hold different parts of the image together for the object as it moves. So, it's an amazing business here of signalling parts of an object, seeing it as one object, combining the parts together so they don't dislocate, although the signals arrive at different times when it's moving. Seeing a circle actually becoming an ellipse in the retina, but we see it as the changing positions of an object. So there are all sorts of transformations here, and a lot of it depending on knowledge that a mug is a thing you can pick up.

If you take computers as a way of thinking about the brain, you've got parallel processing, where you've got the operations going on at the same time which converge, or you do it step-by-step-by-step, serially. Now, the thing about parallel processing is that it's much, much faster, and everything suggests that the brain is a parallel processor. There are different regions that are handling different parts of the problem at the same time, then it comes together and you get the answer. Everything suggests that, and the anatomy of the brain suggests it and a lot of phenomena of perception suggest it, and also the analogy with any sort of information processor such as a computer suggest it. But I think there's no doubt that it's parallel processing. You've got dedicated regions of the brain carrying out special processes and it ends up somehow with a final answer. We don't know quite how that happens actually.

Illusions – departure from the truth

Ernst Gombrich is another hero figure. There are several, I think, in one's life. I have an immense respect for Ernst Gombrich. Well, what happened was that Roland Penrose, Sir Roland Penrose, who started the ICA (the Institute of Contemporary Art), introduced us because he got interested in my sort of ideas about perception. He was a very … he was an artist in his own right and knew all the artists in the world, and organised exhibitions and so on. He was a wonderful man and he just thought this was a marriage made for heaven, you know: my sort of stuff on perception and Ernst Gombrich's immense knowledge of art history and the nature of art in many ways. He actually knew a lot about perception and so he organised this big exhibition that we ran called *Illusion in Nature and Art* at the ICA, which is really actually based very much on my stuff. He said it was, and it was. And Ernst and I ran it, organised it. For about three years we worked on this; quite a long time, and it was a major exhibition which filled the whole the ICA, then went to New York and also to San Francisco. And then we did a book together, again called *Illusion in Nature in Art.*

Well, I think actually defining illusion is jolly difficult. Basically, I think one means by it, if it's say a visual illusion, for the sake of argument, that it's a discrepancy or departure from the truth. That's really what one means; that there's a physical reality out there that our perception more or less corresponds, and when it does not correspond it is then an illusion.

The waterfall phenomena illusion was actually described by Aristotle. He was looking actually at a flowing river, according to his description, and when he looked at the bank, the bank started to flow, to move in the opposite direction. He's actually a bit ambiguous about whether it's the opposite direction or not, but in fact it is in the opposite direction always with these things. Now, what happens is, that you fatigue or you adapt cells in the brain which are signalling movement -- we now know that, that movement is specially signalled, and it upsets the balance of the system so that the cells in the brain that have been over activated, if you like, by the rotating spiral or by the moving river, then give less information or less signal than the countering cells, which have not been adapted. So the movement system is unbalanced and experiences movement always in the opposite direction, and this is purely physiological. It's in terms of the neurons representing motion directly.

Right, well the moon is always the same size at the eye. It always subtends half a degree, it's always the same size, the picture in the eye. You can show that with a camera. If you take a photograph of the moon when it's high in the sky, or when it's low down on the horizon, it's exactly the same size in the photograph, but when it's low down on the horizon it looks a jolly sight bigger. Why does it look bigger although the image is exactly the same? This is the question. Now, the first experiment is to look at it through a tube, which you can get from the bathroom if you like, and as soon as you look at it through a tube, so the surroundings are not there, it looks small. It doesn't look big at all. The illusion goes. It depends on the surroundings, when it's on or near the horizon, and what's happening is that the perspective etc. towards the horizon is scaling it up like in the Ponzo illusion. It's scaled as it were upwards by the information of distance.

Illusions – the blind spot controversy

Well, this is a lovely controversy. There's a huge region in the human, and indeed all vertebrate retinas, which are … which is blind. It's where the optic nerve comes out of the retina into the brain and there are no receptors, light-sensitive receptors, where the blind spot exits the retina into the brain. So there's a huge blind area, which we're not aware of. That's the extraordinary thing. You'd expect to see great big black patches out there but you don't. And you don't, even with one eye, so it's not that the other eye is covering up. That's the important point to make. Well, there's a controversy. One idea is that you simply ignore it. Its like being in a party and there's some incredibly boring person there who never says anything worth hearing, so you simply ignore them. It's as though they're not there. Or, you can say that the brain actually creates what ought to be there from probably the surrounding pattern. And we did an experiment -- I did an experiment on this with Ramachandran, who's really a significant, very important neuroscientist. Indian, lives in America, and we've done a lot of work together, actually. And we had a rather inspired couple of weeks, or so we thought anyway, where we actually made artificial blind regions in the retina so that we could examine the effect, not only far out at the edge where it's hard to know what's happening, but near the middle of the eye as well. We called these 'artificial scotoma', and we did experiments using a computer screen, which convinced us that it is actually a dynamic process of filling-in, not passively ignoring. And I don't think I can really go into the details of this experiment. It's a bit a technical but that was the issue. We came out with the view that it's active, dynamic filling-in, from the surrounding pattern, and there's now actually collaboration of this using magnetic scanning, you know, fMRI, and it's now been measured that there's actual activity in the brain associated with the filling-in of the blind spot. You can actually record the brain activity so we're pretty jolly sure we were right on that.

Illusions – flipping images and the hollow face

There's a recent and wonderful experiment where you get illusory expansion like in the Ponzo, and the corresponding region in the first stage of visual processing called V1 actually changes its size by the apparent size of the illusory figure. So there are beginning to be physiological correlates of perceptual scaling, which is very, very exciting.

The brain can't always make up its mind and I like these phenomena very much. And you get what I call flipping from one perception to another, which *is* entertaining, or trying out one hypothesis and then another. You change the hypothesis. You change the interpretation of the data available. I'd like to show you that with a little model. I've got here a model, which I'll put on the table for a minute and then you'll see, I think, that that's probably a duck, but every now and again it will look like a rabbit. And I think perhaps I'll hold it up, better there. So there we've got a duck and if I turn it around it may look more like a rabbit. These may turn into ears. There, it's a beak. The orientation can change it but it's important to know that we'll flip from duck to rabbit or the other way round without my doing anything at all. Your brain entertains the possibility it's a duck or it's a rabbit. It's ambiguous, and this flipping is spontaneous, showing activity, positive activity of perception -- always trying to seek or select the best possible hypothesis. So these flipping things, very important for relating perception to brain processing. The question then is: does the brain physically change when the thing goes from duck to rabbit? The answer is: it does, but when you change the hypothesis with no change of input to the eye, the brain also changes its activity as you're experience changes.

The hollow face illusion is, I think, in a way, my favourite. I actually found this thirty years ago and I've been sort of living with it ever since. It is very, very simple. It's simply a mask, the inside of a mask, if you like, which is actually hollow so the nose is actually sticking away from you, rather than towards you. But you see it as a proper face with a nose sticking out and not in. I'm going to rotate it a bit so that you'll see, I think, that it is really hollow. As you see, it's going in, and not only that, I can actually, I put it to there, I put my hand inside the mask which is there, really hollow. But as soon as you can see the face as a face, with the features, your brain refuses to see the thing as hollow because it's so jolly unlikely. Now why is this? Your brain knows an awful lot about faces because you experience them all your life and they're terribly important, so it ignores a whole load of information that is available to the eye, that it's really hollow -- shading, changes of size, all sorts of things like this -- ignores all that bottom-up information and it calls up the hypothesis, the perception, that this is a face. Embedded in that is the knowledge that noses stick out towards you when you look at a face, and that knowledge is called up and dominates the perception. And you know intellectually, if you like, that its really hollow. You can touch it with your fingers, you can hear all about it from other people, from yourself; and it still looks convex when it's really concave.

Illusions – Kanizsa and the ghost

The Kanizsa illusion is incredibly beautiful. It's very, very simple and you simply see something that is not there. You see a ghost and every time you look at this figure you see a ghost which isn't there. It's completely repeatable; that's what's so lovely about it, and it's simply a drawing of three cakes, if you like, with slices cut out of them, and the slices aim at each other. But lo and behold, you see something else, which is not really there. You see a white triangle joining up the slices. That is a ghost. It's purely illusory and the edges that you see are not there. There is no physical edge whatsoever. What I think is happening is that the brain is creating a white triangle to explain, if you like, the missing bits of cake -- the slices -- because they are exactly lined up. It's very unlikely that you've got three cakes with all the slices exactly lining up. Much more likely that there's something in front, hiding the cakes, so that the slices are not really slices, they are hidden by the nearer object and that's what you see. So you produce a ghost.

If you put the illusory edge across the receptive field of V1 with a cat, let's say, it does not activate V1. The illusory contour doesn't stimulate V1. It's only further up. It's a postulate beyond V1, higher up than V1. But you've also got to be careful about this because you get fibres in the brain going down, back into V1, so even if you've got an effect in V1, it might not originate in V1. But in fact the evidence is that it's higher up in the brain that these contours are produced.

This is a lovely example of probabilities driving, creating perceptions, and we now think of this in terms of what we call Bayesian theory, from an 18th century cleric called Thomas Bayes, and there's a whole mathematics of this. And the overriding probability here is of a nearer surface or object hiding parts of the cakes. This is so likely that the brain projects and invents it, and you see it although it's not there because it ought to be there on a probability basis. It's a wonderful illusion.

Illusions – Bayesian theory and the probability of perception

Well, Thomas Bayes was a very interesting chap and he's sort of recently become really into prominence. He was forgotten about really for years and years. He lived two hundred years ago, 18th century, in London, and he was a cleric. He was a priest if you like, and an amateur mathematician, and he wrote this paper, which he never published in his lifetime, but a friend of his found it in his papers, got it published by the Royal Society in *Philosophical Transactions of the Royal Society*, which was really a revolutionary idea. Which, it concerns probability, making inferences from probabilities, and it was very much inspired from gambling. He was a priest but that's another thing, and this is the case that the origins of probability theory really came from gambling and they saw gambling as experimental theology -- God rewarding us and punishing us by whether the dice fell in the right way or not, you see. A lot of it actually was done by parsons, who were interested in morality. Very intriguing thing this. Anyhow, his theorem, he developed this beautiful theorem, which I won't go into detail, but it concerns the probability of an event happening against the improbability, if you like, of the perception being correct or wrong. So, if the event is highly unlikely, then the probability of perception working effectively is not enough to convince you it's true. If it's highly likely to be true, then it's … you need very little processing to accept it. So it's in a way a balancing act of what the probability of something out there is going to be against the probability of the perceptual system working appropriately or correctly. And a part of the theory which is very interesting is this: it suggests that you never see anything with no initial probability but what perception is really doing is always modifying what we call a 'prior probability' -- the initial probability. And it doesn't start from zero: there's always some initial probability, which is then modified by perception, and this is really what's going on in perception. And the balance of these probabilities is really a very key idea.

Take the Kanizsa triangle, the ghostly triangle. That is more likely that there's an object getting in the way, hiding the cakes so that the slices are not really in the cake, they are due to being hidden, and that would be a Bayesian situation. It's jolly unlikely that these slices in three cakes are going to line up. Very unlikely. More likely there's something in front getting in the way. So likely that you actually see the thing on the basis of the probability although there is no evidence directly from the eye at all. There are no edges actually signalled.

The real distinction, as I see it, is signals from the world given from the retina, from the cochlea in the ear and so on, coming upwards, so to speak, from the world. And what is coming down is really knowledge. It's really knowledge of objects, and without both knowledge and signals, you don't have perception. If you've only got the top down, you're dreaming. You've got all these experiences and what not, but not attached to reality because you don't have those signals, which are steering it. If you've only got the signals then you are an automaton. You're dependent on real time signals for behaviour and then you can't predict the future. You can't use the experience, you're simply a bunch of reflexes. I think that interface between bottom-up information or signals and top-down knowledge is where the excitement is. I tell you what, it's a nice joke. It's the hyphen in physiological-psychology. It's where they meet -- physiology and psychology.