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**Vision and the Artist**

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Welcome everybody, on a cold January. My task tonight is to talk to you about the eye of the artist.

There are many sources, but in particular, I would like to point out Patrick Trevor-Roper’s now iconic book, “The World Through Blunted Sight”, which was given to me in the late-1990s, before I qualified as a doctor. It is nearly entirely wrong, but so is much of what I am saying tonight, and in twenty years, future research will show just about everything I am telling you now is wrong, but it was one of the first systematic attempts to look at what we understood about eyes and vision and try and explain what might be happening in the images created by famous artists.

A more up-to-date version, “Vision in Art” by Margaret Livingston, who is the Harvard Professor of Visual Sciences and Neurosciences, and she works with David Hubel, and those of you who have been to my lectures before know in what regard he is held, having done the original work on cell recordings in humans and animals.

“The Eye of the Artist” by Michael Marmor and James Ravin, is a multi-authored book that describes in some detail issues to do with eye diseases and how they might have affected the visual arts of those people affected. I am grateful to Tony Harris, who is a pigment specialist and colourist, and Raphael Pepper, also the same, who is a working artist, and some of the images I have taken from Wikipedia.

The link between the eye and objects has fascinated humans since they were first able to think about these issues. We are immersed in this sea of electromagnetic radiation. These waves interact with each other, with other things, they bounce off them, and this cacophony of signals hits us from all angles. Through a tiny little aperture called the pupil, we select out a small amount of this information, between 400 and 700 nanometres – that is 0.0000004 of an inch, so there is a very tiny little fraction of this electromagnetic radiation we choose. We collect a little bit more, which we can identify as heat, and we have got some directional source towards heat as well. So light is nothing special, it is like any other radiation; it is just special to us because we have receptors for it.

Sky light is what interests us, and this is the scattering of short wavelengths of light by molecules, and it is much dimmer than the direct light of the sun, but the sky is a hundred thousand times larger, so this light is very important, and the illuminous contribution is significant. This enables us, for example, to read a novel in the shade.

Different surfaces absorb and reflect light in different parts of the spectrum and they do this differently according to their chemical composition, and how they do this gives them different attributes which our eyes can pick up at a distance and enable us to identify what they are likely to be.

However, light at equal energy but different wavelengths can appear differently bright. Light in the middle part of the visible spectrum, between 500 and 600, appears very bright indeed, whereas light at the shorter wavelengths or at the longer wavelengths is really quite dim, and the amount of energy we need in this light to make it bright is significant. There are several-times order of difference of amount of energy required to see these wavelengths as equally bright. So, in order to compensate for this, we call the unit a lumen, which is, whatever its wavelength is, that would be as equally bright to the human eye.

Now, biology is interested in surfaces and the light reflected from them, this mixture of different wavelengths, short wavelengths, long wavelengths, and these wavelengths just in the middle, and they hit a surface, and if they are all reflected, we will see this as white light, which is a mixture of all these wavelengths together. If the light hits a completely absorbing surface, these wavelengths are attenuated out and we will see this surface as black.

From this information, we are going to react to these local changes in light and we are going to look for shadows, edges, movement, how far away the object is, three-dimensions, its shape, we have got to differentiate these objects from the background, and we have got to look at the overall organisation, the visual sea. In addition to this, we recognise what objects are, in particular and specifically, and we also recognise colour. All of these things have to be transmitted into a painting to give us a realistic impression of what might be going on in the distance.

I will deal with luminance first, the brightness of light. Here is a lovely painting in Germany, which is showing the illumination on the head of St Paul at his writing desk, and we get this vivid impression of reflected light from his head, which is much brighter than the shadows on the other side of his lectern and his books. In real life, this would be somewhere in the order of 100,000 times the difference between this area and this area, but pigments cannot do this. All that pigments can do is a few tens of the order, so we have to use special tricks to get this effect, to make this simulate real life.

Another example is the well-loved painting from the underrated Joseph Wright of Derby, a painting of the philosopher giving a lecture on the orrery. The orrery is the hidden light behind this gentleman here, which is demonstrating the phases of the moon and the orbits of the planets around the sun. Look at the brightness contrast again – we are really getting a sensation of a very bright orrery light. Of course, there is no such difference in real life between the pigments, and this is achieved by predicting what the visual system might be seeing, but nowadays, we have a reasonable understanding of what these changes might be. Interestingly, these faces represent the phases of the moon as it comes around to new moon, to a full moon, and the different phases, which is a really rather nice effect. So the light is not giving us a proportional sensation. The more light there is, it is not brighter, as I have just shown you.

The eye is not a very good light meter, and the reason for this is that it is doing calculations. This particular cell here, if we shine a light on the retina, on the retinal cells, it does not give a particularly good response. It just fires the same as if you fired it in a darkened room. However, if we just use a pinpoint of light on it, it bangs off like a machine gun – it is extremely active. And, interestingly, if we put it in complete shadow but allow light to fall on the cells surrounding this patch, this will also give an effect, and this effect is to completely inhibit. Here, as a shadow comes across, we have more of these cells firing, less inhibition, and once again, it fires up. So what are these cells doing? These are edge detectors, and what they are giving us is information about edges, about the relative illumination of the scene, where it is light and where it is dark and where lighter areas abut darker areas, and this is very useful for survival, and also explains some of these interesting phenomena, such as simultaneous brightness contrast. The amount of pigment, here, the amount of reflectance is exactly the same, but put against a different background, they look shockingly different.

This also applies to colour. It may not surprise you to know that each of these squares are exactly the same, but the background is changing and they are appearing quite differently, and this is occurring because of this calculation that is being performed by the retina before it is being passed on, and the calculation is not being done by photographic film.

This is a print from the oldest photographic negative in existence, and those of you may recognise it is the window in Lacock Abbey, taken in 1835. Obviously, the human eye, although it is not a light meter, like this photographic film was, is doing a lot more than that, as we saw in the folds and the darkness of the beautiful Rembrandt painting.

This centre surround where the central cell is inhibited by its surrounding cells, has been used to explain a number of effects. We can get effects of three-dimensions, as you can see in this purely neutrally coloured disk. Only the background is changing.

Using changing backgrounds can give us height and sense of darkness, such as this painting by Seurat, where he has used these edge effects and gradients to highlight the darkness of the bow on the back of this lady’s dress. So, gradual changes in background can stimulate the opposite shift in the foreground, and we really understand why this may occur.

From the retina, we are going to wire this up to this little relay in the mid-brain and send it up to the orange peel on the surface of the brain that is highly folded, and it is highly folded to give it a massive surface area, and this little bit in the groove in the middle at the back is where we do all the vision processing, where we are going to extract information out about colour and opposing colour. We are going to extract about movement and shape, which has its own specific and fast channel over here in a different part of the orange peel of the brain on the surface. Different parts of the visual scene are being analysed differently. They have their own private channels, for colour, for acuity, for form, for motion, for stereo, for depth, and this parallel processing in these multiple computers is what is giving us this rich perception of the outside world. This has to be mimicked by artists to give us any realistic interpretation of what might be occurring in their paintings.

Very simplistically, but pretty correctly, it was realised by early workers that there may be two completely different systems. There may be the aware system, which is the oldest one, evolutionarily speaking, which detects motion, space, position, depth, three-dimension figure on the ground, and the overall organisation of the see, and the more developed, more recent system in primates, which is divided into two, the form system, which uses colour and movement to determine shape, and the colour system, which is of low resolution and tells us about the colour of surfaces, helping us to give object recognition. When these two are not working in sync, as I will show you, you can get some extraordinary effects.

One of the things that has been used to explain this particular feature, which is where we have a gradient and, between two different coloured surfaces, a light surface, a dark surface, we have a little bright band and a little dark band in the gradient, that is what we perceive – a little bright band here, a little dark band here. Actually, they do not exist in real life. This has been explained by these cells in the retina, as you can see, so we have got four with negativity, so it does not fire, only to the positivity. As it moves into the shade, there is a big burst of activity, so we get lots of positivity from the inhibitory surround, which is stimulated by black, and the centre, which is stimulated by light, and then, as it moves into the dark, it goes back to the low firing rate again. This looked very plausible.

However, this has been challenged by Dale Perd. He says that things like this are not very common in nature – God does not go around painting the world with little gradients, giving us a perception of sharp and white bands. Humans do that. What God does is shine lights on things that give this, which is a curved surface, that has a different luminance, and so what this is doing is actually mimicking what we see in real life as curves, which is why we make this imaginary bright band and this imaginary dark band, which is exactly what is going to happen if we scan across a folded image or a cube or a three-dimensional shape.

Nevertheless, map bands has been used to generate some beautiful images, most strikingly by Victor Vasarely, whom we have previously discussed in a different context in op art and you may be interested to know that some of his paintings were sent off by the Russians on their space trips, presumably in case they came across other animals in the universe that could actually interpret map bands and had a similar visual system to us – and probably spoke Russian or French.

This, however, is not new. In the first century BC, walls were decorated with architectural features.

At this time, rooms had become a little smaller. The population was growing. The real estate people were making small fortunes, and the poor people were put into ever decreasingly dark, windowless, tiny, tiny apartments. So, in order to make this bigger, what you want to do is paint the walls and give them an illusion, as if it was receding out, which made your room appear larger, and how they did this was to paint little map bands, light, gradient, dark, giving a very realistic perception that this is a three-dimensional space to look at. This is done long before linear perspective. There are no particular elements here that we would recognise as Renaissance perspective, but nevertheless, it gives us a very vivid, real sensation of three dimensions. So that is what map bands are about: they are about change in luminance.

My favourite painting, originally was called the Wedding of Arnolfini, the Marriage Portrait. We now know that is not true because who it was alleged to be had died eight years after this painting was actually done. We know the date of the painting from this little section here, where we have “Johannes van Eyck fuit hic” written on the wall here, and the date, so we know exactly when this painting was done, and this lady, who was his wife, had just died. Now, allegedly, she is not pregnant but – because this posture does not represent pregnancy, except in Peter Jones, and if you looked at Peter Jones, you would see lots of pregnant women who are exactly in this same posture. What is also interesting is, behind, on the bedstead here, is the saint of pregnancy and childbirth. It is possible that this lady died in childbirth, and in which case, this painting is a celebration, it is a love painting, celebrating his wife who died young.

Under some circumstances, targets surrounded by areas of higher luminance can appear brighter, which is the opposite of simultaneous brightness contrast. So if you look here, these grey stripes appear brighter than the same grey stripes are appearing here – well, they should be now, but it does not happen like that.

It is also showed with colours, and Willhelm von Bezold showed this with red, which I have illustrated in a previous lecture. So what is going on here? We cannot use that retinal explanation to say that explains this, then how does it explain this? We have got to be thinking there must be something else going on, and that is why I am saying a lot of this stuff that we are looking at now is very early in the days of interpretation, and as we know more, especially with magnetic resonance imaging, we are finding out more information.

If we paint a gradient, going slightly darker, and then slightly darker again, we get an image that would appear that this is darker than this. However, it is not. They are exactly the same brightness. So, what is it in nature that might give us a little gradient on both sides? It’s where you get a fold on a cube, and we would mostly interpret this as a three-dimension, as a cool-box. You know, we know that that is full of yummy stuff to drink on the beach, do we not? It is actually the same colour as the cool-box, it is just that we are seeing it differently because we are interpreting it as if the sunlight is affecting it or the beach is affecting it from below, in this particular instance.

Here, we can see a very realistic three-dimensional interpretation of this. Lotto, who is now in London, is saying that, when we see this artificial construct, our brains are going to interpret this as what is more likely in real life, and that is not bits of paper littering up the scene that are painted with a little gradient in them. What are more likely to be in the visual scene are rocks and stones, and cool-boxes full of beer.

This window appears very bright indeed. In fact, it is almost so dazzling that in real life you feel you want to stand back and not look at that window. This extraordinary effect is made by pigments, but down here, where they are nearly completely black, and here, are only fifteen times different, not that 100,000 times difference in the real scene. Rembrandt here has given a fascinating, realistic interpretation of what is going on in real life, and how he has achieved this is by these dark abutting light with gradients, and he has fooled our visual system into thinking that this is a very vivid, differently illuminated scene – very clever.

It has actually been used similarly to give us perceptions – the river down here appears bright, the mountains appear dark. They are actually not, they are the same brightness, and this is achieved by these gradients.

Hsu Tao-ning was originally an amateur artist who was a medicine seller in the Sung dynasty, and became, developed his own unique style, and these beautiful images, where he is just using gradients of charcoal to give us a three-dimension effect.

And it was not just him. If we look here at Picasso’s painting, we are just using luminance gradients to generate a very realistic interpretation of three-dimensional cubes, within which we can see the face of Daniel Kahnweiler. Of course, Picasso quoted, “What would have become of us if Kahnweiler had not had business sense?” implying that nobody was going to buy this rubbish unless Kahnweiler had persuaded people it was good art. We will return to that subject later.

I want to stay with luminance before I move onto things that might interest many of the audience here, like colour and motion, because we have a second luminance channel. It is this one, and this luminance channel kicks in in the dark, in dim light, in moonlight, and you can see it is brighter now in the shorter wave-lengths. This is our normal luminance channel. This is switched off. There is not enough energy to stimulate these cells in moonlight. Unfortunately, we only have one set of these cells, they are called rods, and these are brighter here, which is why things appear bluer in moonlight. Moonlight actually is not bluer than sunlight. It is actually redder. If you shine a little light meter on it, it has a surface that is red, like the surface of Mars. Also, it is not very reflective at all. It has got the reflectivity of a piece of coal - about 13.6% only of sunlight entered onto the moon is reflected, and so that makes it about 500,000 times dimmer than the sun, so how on earth do we see? It is the rods.

We have only got one sort of rods, so we cannot compare different wavelengths, so we cannot get a sense of colour, we cannot differentiate between wavelengths. All we can do is say how bright something is or how dark it is and in order to mimic this is very difficult.

Paul de Limbourg and his brothers made a good stab at it in the early 1400s, in this beautiful book of prayers for John, Duke of Berry. Now, there are several things that are interesting: firstly, we see the blueness; secondly, we see the lack of detail; and thirdly, we see the sources of illumination. There is a little warm illumination here from burning embers, but the main source of illumination is emanating from Christ, and this is very important. It symbolises divinity and hope in this otherwise awful scene that has been painted here.

Joseph Wright of Derby painted this beautiful image of Dovetail, with these gorgeous greens and gorgeous colours – a good early attempt. We know that this is not what is seen by moonlight, so he has gone out there at moonlight, done some sketches, he has taken it back in, he has painted it in his own building, with dimmed but not entirely dark light, and it is wrong on many aspects, although it is a beautiful image. The light is not actually blue, as I have said before. The receptors that see short wavelengths, they see those as brighter, that is all, and it cannot see red things very well. So the moonlight is not exactly silvery – there is no inherent silvery quality about it.

How were these scenes painted in other traditions? They were painted by using luminance in specific areas. So the lamps alight in these houses give a sensation of evening and dark.

Turner made a really good attempt here. This satisfies me to many degrees. We have got the luminance appearing brighter in the illumination of the moon. We have got the redness of the lamp on the boat and the charcoal burner. We have got loss of detail entirely in the sea, and very poor detail in the peripheral field.

A hundred years later, which I think is particularly beautiful, he has used this silvery effect, which is something we see, although the light itself is not inherently silvery, and a beautiful attempt to reflect the moon correctly in the height of the sky.

This shift in what we call scotopic vision. This shift to the dark gives a pale grey, greenish scene. Shapes with a lighted value just have an outline on them, with no detail at all, and the dark shapes, there is all internal detail, what we call low contrast detail, and there Is reduction in our sensation of movement. It Is quite dangerous to move around at night-time if there is lots of moving predators in our visual field because we cannot see them very well.

This all wires up in the back of the brain, from the retina, but the brain does not use those simple on-off little tiny circular fields. What it uses is much larger receptors that are very sensitive to the orientation of lines and to movement, and this is processed by simple cells passed on to complex cells. Each one of these columns reflects a different part of the visual scene, so our visual scene is mapped entirely by directions. This is sampling this area, and in this area, every single possible orientation of lines is assessed. Other aspects are assessed as well, such as colour, and we will come on and talk about that later on. Lines are very important parts of our vision.

In fact, we do not need to draw very many lines at all to generate a realistic three-dimensional visual scene, as we can see with Ghirlandaio’s view painting. What he has done is to draw a cartoon with minimal amount of detail, just blobs for hands, no detail at all on the faces, and a rough three-dimensional architectural scene that ultimately is going to be transformed into a gorgeous fresco. If it were a cartoon full of pinpricks, it would have been destroyed as this painting was being made. So we do not need all this detail. Just this alone is enough to give humans a very vivid sense of what is going on.

His pupil Michelangelo said he was self-taught but then learnt an awful lot from his master and was involved in many drawings for his master when he went to work with him in Florence. This is the study for Adam for the Sistine roof, just lines on paper for this beautiful three-dimensional image. Of course, just some outside lines and minimal shading gives us a very good realistic interpretation that this is a map, as do these.

Pablo Picasso reduced this to extraordinary lengths. He could draw, as we know. He could also draw things with just one line…Le Chien. This was his favourite dog, called Lump, and Lump became famous because he actually ate a Picasso, which meant that his stomach probably had the contents of the most expensive meal ever eaten by any dog ever in history.

Picasso loved these little one-liners, and there are many examples of them. Even a human being can be realistically placed by just one line. This is how good our brains are at detecting lines – and we have got a separate, private channel that does this, and artists know that, without having been taught it, and that is why they can get away with this, and we all know that that is a dachshund.

Furthermore, processing these lines is so strong that we can actually see them passing illusionary where they do not go. We get a vivid impression here that this is a square shape in front of the line. The more lines we put on, the more vivid the illusion gets. We think lines are continuous. We do not like spotted lines. We want a continuous line, so we imagine there is something white in front of it.

This is called a Kanizsa figure, and again, there is no triangle here. In fact, there are no triangles whatsoever in this. There is a little pack-man here, there are two Vs, here, and there is nothing here, but we have got a realistic interpretation of several things going on. We now know this is processed, not in the primary visual area, but in the next one on that I showed you, and if you feed some people some radioactive sugar and you show them this image and you give them an MRI scan, you would see this second area lighting up. There are more cells in this second area, called V2, Vision 2, than in Vision 1. So this type of stuff is being processed further downstream.

The second thing we are going to talk about is acuity, how many things can we see in a small part of the visual scene and how sharply we can see them. This, traditionally, is checked by the Snellen chart. This enables us to see things very sharply, in fine detail, but that is a bit difficult to do research on, particularly if we are going to do research on things like animals and children. What we do when we are experimenting on them is to use these grids or spatial images. At a lower contrast, they are more difficult to see. Here, there are more spaces or more cycles of this grating per degree than there are per degree here.

I think it is a wonderful image of our dear leader, which he transforms slightly here, and then uses this image, which is full of high spatial detail, to put it into a low spatial image, where we are still able to recognise the cheek, the nose, the ear, but by the time we are getting near to low spatial frequencies, we are losing the ability to recognise this as a portrait of a famous face, and by the time we just go to very poor spatial detail, and low contrast, there is no recognition that this is the same as this. So, the acuity and contrast are very important components.

This is Poussin’s Death of Germanicus, in Minneapolis, and it is a beautiful painting. It is an astonishing piece of work. However, it is visually unsatisfying. What I found difficult is not the colour, it is not the image, it is not the spatial – all of this stuff is right. This is an expert painting by an expert painter. Looking at this, why it is unsatisfactory is because the detail is too good everywhere, and we know that is not true. We know if we look straight ahead, there is loss of detail, so this painting is not actually giving us a very good representation, and that is why it appears to be unsatisfactory, because it is trying to give us a good representation of reality.

We can avoid some of these traps by just not finishing the rest of the painting, which happens here with Dante Gabriel Rossetti and this very beautiful image, but he just did not finish the rest of the painting so we concentrate on the face, which is rather nice.

Peripheral vision is very strange. It is not just blurred central vision. It is entirely different, and it is wired up differently as well. As we have said, over 150 years ago, one either sees something black of indetermined form or one sees two points. So if you look at it, you see the two points. If it is over here, you just see this blotch. We use peripheral vision in a subconscious fashion.

This is a Grand Master in chess who was asked to quickly appraise this in five seconds, and then it is taken away from him and then he is asked to place the pieces on the chessboard. Now, he can do this even though he has not even looked at them. We know where he has looked, because there is where the contact lens with a little pointer tells us where he has looked, but he knows where everything else. Self-conscious perception is occurring here and giving very detailed and accurate information, and we are doing this every day. You do not have to be a chess master. Our visual brains are very clever, and we should all give ourselves a Nobel Prize on the way out because they are the cleverest things that have ever been invented.

What is slightly different that makes other people cleverer than some of us in the room, me in particular, is to be able to represent this, and this is why, in England of course, we like these paintings. These are British! Furthermore, they represent exactly what I am talking about. This central bit of vision here is painted very accurately, tiny brush strokes, beautiful detail of these windows, but in the periphery, there is just broad brush strokes. There is no detail on the leaves whatsoever, just a clump and a lump, and that is exactly how our visual system works. This is why Constable is better than the French, until this date, because the French, not being stupid, are going to catch up, and they are going to invent something called Impressionism, but they have not invented it at the moment, so there was a moment where roast beef was ahead of frogs’ legs, but only very temporarily.

As I have said, this part of our visual brain is wired up completely differently. It is completely different vision, but it is processed simultaneously at the same time as our central vision to give us a visual scene. Colour is processed entirely differently but it is processed simultaneously to give us a very realistic sensation of the visual scene. Luminance and shape are also coded in entirely different parts of the brain and have their own separate channels. This is what is called parallel processing.

There is one thing still missing from this gorgeous image: there is no sensation of movement, and that is very hard. Before I come onto movement though, I will talk a little bit about colour. We remember Newton, who split up colours and found orange, and then he found orange could not be divided into any more colours through another prism, but he could mix yellow and red and get spectrally the same orange, and if he shone through a blue filter, he would get blue light, and all of these lights would be blocked. Well, hurrah for Newton. This had been known for some time.

Abbot Suger, who rebuilt Saint-Denis and put in the beautiful blue glass, did this deliberately. He was very much influenced by a book called Pseudo-Dionysius, which was apparently written by the 5th Century anonymous theologian. It was ascribed to the Athenian convert of St Paul, the Areopagite, and that is why it is called Pseudo-Dionysius, because it was not this guy who actually wrote it. But it does contain lots of Neoplatonic theory about colour and light. You see, God has this perfect light – all light emanates from God and that is love, this is divinity, and from this emanates movement, which flows from this and allows us to see the world. In fact, making something that is opaque, like lapis lazuli, and fusing it with materials to make it transparent, into this beautiful blue light, was something that is quite magical and quite divine. Furthermore, the materials were very expensive, and Suger quotes of it when he says “materiam superabat opus”, the workmanship surpassed the materials. That is why these are beautiful. Unfortunately, none of them exist, so do not go to Saint-Denis, for two reasons: one is it is dangerous – it is on the outskirts of Paris; and secondly, none of this is here. There are two bits of Paris: there is the nice bit where the tourists go to, and there is some bits on the outskirts that you need to know what you are doing.

This is where you go to see what he is talking about – this is Chartres. This is one of the most amazing works of art in the entire universe that I have ever been to, and if I go to Mars, I will be surprised if they ever have built or ever will build anything like this, despite Rover finding evidence of life there. It is astonishing. It is French. It is gorgeous, and it is full of these beautiful images and beautiful colours, using colour to define form and using colour in a way to define divinity as well.

What Newton did that was clever was to say, not only does this transmit colour, he put the two ends together and found out he also got some new colours that do not exist in the rainbow or in the spectrum, and these are called non-spectral colours. What he realised was we could wrap this all round and make a colour circle and then we can do some maths on it, but unfortunately, he did not account for artists, who then started to say, ah, we can now mix and these are opposing, and this is where the theory of opposing colours started to come from.

He did not say you could use this for pigments. He recognised what pigments were. He said what happens when we shine white light in, cacophony, mixture of all these wavelengths, it absorbs all of them except the medium wavelength and this comes out as green and we see this as green. So, what we are hoping now, colours are merely surfaces that are reflecting certain parts – red surface reflects the red and absorbs all of this. We can see this spectrally if we look. Here is a blue paint, in the short wavelength, green, and here is red, reflecting in the longer wavelengths. You will have noticed that, before, I missed all this out because I did not want to mix up colour with luminance. We are going to mix that up in a moment.

There are other spectral colours – purple. Now, purple does not exist. Violet exists at the far end, and if we shine a very low wavelength light, we get a very defined image of violet. However, purple is another reddish-blue that can be generated by mixing red and blue, and this occurs because, at the bottom end of these receptors, you see they have become responsive again. The red receptor, if you like, which actually is mainly orange, has another little peak here, so we are getting two signals, and the brain signals this as purple.

You know I said you could not make it brighter than the paper? Well, you can nowadays, and you can use these day-glo colours, and how these work is they absorb, they reflect the normal, but they also reflect some more, because, when they absorb these, they put some energy into some photons which then re-emit further down as these pinks and reds and give us these vivid, brighter than sunlight, allegedly, reflected sunlight images.

We can also make colours by interference, and there is a variety of ways of doing this, from oil slicks, and we can measure the thickness of oil slicks. Where we are getting these colours, thicker, and these colours where it is thinner, and these beautiful effects. It is also used in the animal world, where we get little interference patterns depending on regular gratings. This was recognised a long time ago by former Gresham Professor Robert Hooke, in “Micrographia”, fantastical colours of the peacock’s wing, and Sir Theodore Mayerne, a little earlier, who predicted that they shone curiously like stars and cast about them sparks of the colour of the rainbow.

This has been used by Damien Hirst. We asked Damien Hirst the reason why he had used real butterflies – 9,000 butterflies had to be killed to make this beautiful, beautiful painting, and he said. “I am become Death, shatterer of the worlds,” which was actually quoted by Robert Oppenheimer after watching the first atomic bomb going off. “I wanted to use real butterflies and not just pictures of butterflies because I wanted it to shimmer when the light catches them, and only real butterflies do.” So you cannot use pigments. If you want to make extraordinary things, pigments are not enough to give us what we are seeing in the real world.

So what about the colour brown? You cannot buy a brown light-bulb, because brown is essentially just dim yellow or yellow seen against a different background, as you can see here. These are exactly the same colour, but they are appearing quite differently according to their background. So, browns are compared to the white they are on to give us a vivid impression of different colours.

So there is a number of ways we are generating colours, and the spectral reflectance alone is not necessarily a predictor of what that might be.

Goethe comes into the fore. He talks in a very complex, difficult language that is based much on Aristotelian theories of light, but he was essentially saying that Newton was wrong and saying all about wavelengths, the mathematics and physics, this is a scientific coffin. So this ad hominem attack against Newton was not very popular by people in Cambridge, although it was tremendously popular by lots of artists, including Turner, who then went, straightaway, after reading Goethe’s book, and painted a painting according to Goethe’s theory, where, from yellow light and blue light were generating these wonderful colours. Yellow is the first colour transmitted from light. It then undergoes a transition, becoming darker when it reaches its peak, and then it develops a white light, which is colourless.

Although there are three types of cones that give us a very rich experience of colour, and this is the diagram you see in most of the books, this is the actuality. There are far less blue cones than there are long wavelength or medium wavelength cones. How does this work?

If we fire a hundred photons at the long wavelength one, we will get, at 6.50, we will get a response of one plus. If we fire two hundred cones at it, it will be a bit brighter, and so we will get another response, which is double the brightness. However, if we fire a hundred cones over here, we will get four times the response. The orange is much brighter to this cone than this is, and we can measure that, and if we measured it out, we could make colour triangles and so on and go on and inform the modern colour theory.

However, Goethe was partly right: psychologically we do not see colours in that way. We are comparing colours because we have comparison maps, not only in the retina, but in the thalamus as well. We have these three channels which we showed you before: the small cells which are channelling information about the difference not only between brightness and darkness, but between what the wavelength of that light is, between adjacent areas, so we are going to get information about edges from colour, but we have got this colour-blind channel which is luminous.

We cannot go far without talking about the theories of the 19th Century artists in France. So, we realise, if we mix a bunch of these colours together, as if they were light, we end up with muddy grey, and any artist or budding artist at school realises this is true, and they realised they could not quite get the vibrancy. So, what they thought, they would put different colours together to get a vibrancy of colour, and this led on to Pointillism.

We know that the simultaneous view of these patches is not the origin because it does not depend on the distance you are at, which it will do for those visual fields that I was talking about before because they are of a set size, so the distance you are from a painting is definitely going to affect what you see. There are certain aspects of this that are not fully explained at the moment, and it is certainly not optical mixing.

Luminance and colour, working together, can generate extraordinarily beautiful images, and in fact, this image is so well balanced between colour and luminance that if we ignore the colour image and just look at its black and white, it looks like a photograph. These colours have been chosen deliberately to give this beautiful and realistic image. Normal human beings cannot do this because green looks brighter to us, and for blue, we have got to have a very bright blue to look anything like a dim green – same with red. A trained artist can instinctively do this and get those colours right, and that is why that hangs in the National Gallery and my daubings are used at the bottom of the cat tray.

There are other sorts of artists, and they work in the private sector, in corporations, and they develop also using colours in a very clever way. This is the original colours of Gulf Oil. Those of you who have travelled with me in the car when I have said, “Stop, stop, stop – I want to take a picture of the petrol station!” know why, because there are very few Gulf Oil petrol stations around, but when you look at them, that is their colour. However, when they set up the racing team, with Steve McQueen and all that cool period they had, these were the colours that they specified, which are actually the colours of Wiltshire Oil, which was a bit extraordinary. What is wonderful about them is that the density of the colour here looks massively different. However, switch over to the black and white, just the luminance channel, and in fact the density difference is not as much, so we are talking here of what is known as iso-luminant colours.

If we look at a painting with iso-luminant colours, this is actually quite disturbing to look at – it is unsettling. As we scan around it, bits appear to move and change, and in real life, if you are not getting that on here, do go and see it – it is Richard Anuszkiewicz’s Plus Reversed. But if we look at it in a grey image, we can see there is hardly any difference.

We are using iso-luminant colours here, and because we have got the different channels, they are not matching up. The colour channel is telling us something different from the luminance channel, and it is jarring, and it gives us something floating about in front of the picture frame or just behind it. These effects are deliberately used.

Colour is also important in defining shape, but we do not need to fill in the whole shape. You can see here, distinctly, this pastel yellow against the white. In fact, it is the same colour, but using this fools the edge detectors to fill it in. We do not fill in colours on a shape at all. We just look and we broadly say that is red, and I do not look at each individual pixel in this room and say that pixel is red, that pixel is red, that pixel is red, and all the chairs – I assume they are all red and automatically colour it in. This is similar to JPEG compression. It means my brain can do other things, like work out where is the nearest place to here for a lovely pint of beer, rather than thinking about what is the colour of every single bit of this rather dim room, and also remind me where my tie is and where I have lost my scarf and where the keys are to get back into the house. So my brain has got other important things to do, rather than pixelating and making immense calculations on colour, so it does not bother.

You see here a distinct neon colouring, where the brain has filled in colours which are not there. There is no colour painted in here. The only thing that is coloured are the tops of these circles. We know that this occurs in the brain here, and we can generate some extraordinary, beautiful effects.

How does this work in real life? Well, Matisse realised you do not have to do dot to dot colour. What you can do is you can leave your reading glasses on and just splot it on – no one will mind, because it looks fantastic, until it is pointed out to you that actually, here, it is not filling the shape, here, it has gone over the shape. But yet, if I had not have told you and you had just looked at it, you would look at that and think that is pretty good work of art. In fact, they were originally exhibited in 1905 with a bunch of other guys who thought in the same way, and this particular exhibition was held in a room in a salon that contained a beautiful Renaissance sculpture, and the critic, Louis Vauxcelles said that “Donatello parmi des fauves” – this is Donatello with the wild beasts. I do not think he liked the paintings very much. But what Matisse had discovered was you did not need to use hue, as long as the luminance was appropriate. This is work that was done by Margaret Livingstone, and you can see this in her writings and in her book. So, despite unrealistic colours, it does not matter – we can still see the shape.

Not allowing Matisse, being French, to better us, I thought I would have a go at this myself with a picture. Here is a very famous image of a very famous person, which I have just put in with unrealistic colours, and we can see all the images of this being a face – it does not give us a problem here.

We can do another one. Everybody knows who this is. There are no realistic colours in it, there is no detail, yet our brains specifically are able to take this out and say who it is. IMAGE

We have to now leave colour, unfortunately, much as I would like to talk a little bit more on it, and talk about three dimensions and distance and depth because that is important. Images on our retina do not tell us anything about the world outside at all, which is very surprising. So, if we want to know where something is and we want to fool someone where it is, we can layer them on top of each other…so things up here are further away than things down here…and we know that from the size constant solution that we have spoken about before.

We can also analyse because the images between the two eyes are slightly different because they are 65mm apart, so there is 65mm divided by the sine of the angle that works out how far they are apart, and that just about is enough to make the vision. These are actually two different images, but they are only subtly different, and this generates, when we fuse them, a very realistic three-dimensional image. We can fuse them in a number of different ways.

We can also fuse disparate images using special glasses and we can watch a 3D picture, as we can see here. This gives a semi-realistic, I would say, impression of depth.

The other way we can do it is by shading, and we can see very realistic sensations of shading, but, you see, this is the colour-blind channel. It does not work with colour. That looks flat. These look a bit bulgy-outy and a bit bulgy-iny, and they look very bulty-outy and very bulgy-iny if you get it right.

This has been used since ancient times – Gerard David, “The Rest on the Flight to Egypt”, 1510, using these beautiful shades to give an impression of three dimensions.

That can be affected by camouflage, deliberately, so the white under-painting of antelopes is used in nature so that we cannot see them against the rocks.

It was used on these cannons in the First World War, and as they went through the streets of France, Pablo Picasso was pulled on his sleeve and asked to look at them and he said, “C’est nous qui avons fait ca”, “It is us who made this,” as he was appalled by what his art had enabled the killing machines to be developed into.

But we can also disguise ourselves against killing machines. You cannot disguise a warship or a merchant ship – it is just far too big, so the torpedoes will always get it. What you can do is disguise how fast it is going and what directions it is going in, and you can do that with basal paint.

This is a lovely painting by Norman Wilson in 1917, which is the dry dock at Liverpool.

You can also use perspective, which was suggested by Baker to make these real images, used in the early Renaissance period, and then later on, with this painting that was actually hidden for 400 years behind an altar, by Masaccio, to give very realistic impressions of paintings going into the background, much more realistic than was achieved by the [Roma] trompe-l’oeil that we saw earlier.

Linear perspectives developed from this, and gives very realistic impressions of depth and, again, this is going to be interpreted in different areas of the brain. Motion, itself, is very important. It is a very specific thing. It is specific exactly the same as colour is specific, or taste or smell is.

Here is a photograph taken of a busy scene. Nothing has been recorded on this slow film except for the man having his shoes shined. This is full of horses and carts which were not even recorded. In modern days, we have got very fast film, the diga-film, but we get no impression of movement.

In real life, we have a delay system that fires, delays fires – if this neuron fires at the same time, we know that has moved from there to there. That is a specific sense. Trying to do this in a painting is very difficult.

So we could try Giacomo Balla, with this painting of the dog and the lady walking along, and this gives us an impression of movement. He then experimented further, more abstractly, “Speed+ Sound”, “Velocita astratta + rumore” in 1913, and a series of other images by this famous artist.

However, this had been done before. In fact, it had been done 32,000 years before. Look at this image here. You can take these apart. It is actually a realistic movement of the head of this animal, and if you look at it as the light goes upon it, in a different way, you can imagine, with this torch going and the horse will move in a realistic way – and to the other angles painted on this.

We can get illusionistic impressions of movements just by painting different darknesses and brightnesses, and some of these can be quite intense, upsetting, and even induce motion sickness, due to the various ways we cleverly paint this to fool the motion detector.

Some of these effects can be quite extraordinary and give us really good impressions of three dimensions, and if we are able to harness these, we can break this camouflage and see the shape of the dog.

And, very finally, what I am going to do is to say a number of artists had bad eyes. The commonest thing that they had was being presbyopic, unable to read, reading, as we get older, the opposite of short-sighted. The ancient artists may have been short-sighted, as was shown.

These were the short-sighted artists, to be able to do these very tiny gems and make them. They may have had magnification. We certainly know, later on, there were magnifying lenses, and in order to do this beautiful work must have required either short-sightedness, extraordinary youth or magnification.

This is the Cairo page of the Gospel according to Matthew from the Lindisfarne drawn by Edbe.

Spectacles came along a little later and may have helped people like Hugh. This is the first depiction of spectacles in painting. There may be older depictions. There is one in Salisbury on a sculpture. And they are used more often – he is using spectacles to read, he is using spectacles to do the libation, and he is using spectacles to paint.

Vincent van Gogh may have had visual aberrations, chromatic, which are normal, but they are quite excessive here in this painting.

And cataracts may have been an effect of Turner in later life. We know Turner wore glasses – I will show you images of him.

Monet was alleged to have glasses to have painted like this, although that is highly controversial and will be discussed at some later point when we talk about expression of culture in a later lecture.

And these actually are Turner’s spectacles, and since currently I am lucky enough to live in the same house Turner lived in when he painted his paintings of London and the River Thames, I somehow have some interest in this, and looking at the sunsets as they set over the Thames, they are really quite beautiful.

Astigmatism was where a focus is different in one plane than the other, and was allegedly set out to explain why El Greco may have had elongation of his paintings. In fact, that is probably not true because you have elongation in different dimensions as well, and it is more likely, rather than him having astigmatism, he was painting trying to fuse the Byzantine style of icons with Western art, where he had now moved from Cyprus and was actually having to make his living in the Western tradition.

Realistic interpretation is very difficult. We may not achieve it by paintings and pigments alone, but we might achieve it by video-gaming, and next year, we are going to explore that and why that is much more realistic than daubs of paint.

However, history tells us that the Ancient Greeks may have been very realistic about it with the competition between Zeuxis and Parrhasius which is described by Pliny the Elder, where they exhibited a painting contemporary with this and the birds flew down to peck the grapes. So, Zeuxis says, “I am obviously the greatest because I can even confuse the birds, who are renowned to have very good eyesight. Draw back the curtains and show us your painting then.” He said, “My painting is the curtains…” Zeuxis, arrogant and disliked, actually did say, “I have deceived the birds,” but Parrhasius has deceived Zeuxis.

I think it is unlikely that paintings on board will ever achieve a completely satisfactorily realistic interpretation of the world out there, but nevertheless, they create fantastically beautiful objects and hopefully I have shown you how we are starting to work out how these effects might be achieved by the wiring up of the visual system.

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