Title: Through the Looking Glass: How Your Eyes Decode the Light Show

Part 1: Visible light is an astounding phenomenon of the physical and living world. Yet, it really is nothing but a series of waves travelling from one place to another, no different to radio waves and X-rays. But what makes visible light so unique is that it can be detected by the human eye.

In today’s episode, we’ll explore how the human eye detects and processes light. We’ll dive into the nitty-gritty of the biochemical reactions that unfold in a ceaseless cascade within the neurones of our visual system, enabling meaningful information to emerge from something as abstract as waves of light.

My name is Ivan, and this is CortexCast.

Part 2: The human eye is an incredibly sophisticated structure. It can transform what might appear as completely meaningless waves of light-carrying particles called photons into colour, shape, motion, contrast, depth. Into sensations that we call vision.

At the heart of this transformation is a thin layer of neural tissue found at the very back of the eye, called the retina. The retina performs one of biology’s most challenging feats — converting waves of light into precisely timed electrical signals, which are then interpreted by the brain as a coherent, visual experience.

The principle that underlies this process is surprisingly straightforward but remarkably elegant. In fact it is so simple and effective that it forms the foundation of almost all biology. The best way to think about it is a relay race – a race in which a team of athletes work together by passing along a baton at each stage. In our case, the athletes are the myriad of molecules that abound in the neurones of the eye, talking to each other in the form of chemical interactions and shape changes.

When light is shone over the eye and the claxon of our molecular race sounds, a molecule called retinal sets in motion. We say that retinal is a photosensitive molecule, which means that it undergoes a change in shape when it gets hit by light. You may recall the old adage about carrots improving eyesight. This is certainly true at least in part, because carrots are rich in vitamin A, the compound that the body uses to make retinal.

But retinal is only the start. It sits snugly within the central crevice of a protein molecule called rhodopsin, the next athlete in the relay. Rhodopsin is quite special in that it can feel when retinal changes shape. Upon doing so, rhodopsin changes shape itself as well and by this same principle relays the message to the next set of molecular players. Those molecular players communicate with the next ones, and so on. This domino effect culminates in the opening of a massive array of tiny floodgates in the membrane of the neurone. When this happens, charged chemical species called ions, specifically calcium ions, rush across the membrane, out of the neurone, and into the surrounding space. And now, having lost electrical charge, the neurone becomes electrically stimulated. And *this* is the cornerstone of communication in the nervous system: neurones becoming electrically excited and transmitting impulses of their excitement to each other.

Part 3: So, let’s summarise where we are so far. At this point, light is shining on the eye, and neurones in the retina get electrically stimulated. These neurones, by the way, are a special class of cells called rods and cones, which you may have heard of before. They are so called, well, because they resemble tiny rods and cones when viewed under the microscope. The difference between the two is that cones are responsible for detecting different colours of light and providing high-acuity vision. To this end cone cells contain different variants, or flavours, if you like, of the rhodopsin protein, with each flavour being sensitive to different wavelengths – or colours - of light. Rods, on the other hand, have just the one type of rhodopsin, so *cannot* distinguish between different colours. They *are*, however, overall, more *sensitive* than cones. We say that rods confer scotopic vision – vision that is useful in environments with low light intensity: in a dark room or at nighttime, for example. Another interesting feature of colour-sensitive, or chromatic, vision, is its localisation to the centre of the retina. You can actually investigate this yourself right now. Take any object that is around you and place it into the palm of one hand. Now extend your arm fully to one side at eye level, look straight ahead, and then gradually bring the arm towards the centre of your gaze. You will notice that the exact colour and shape of the object will become clear only when it approaches the centre. The reason for this is that cone cells gather very densely right in the middle of the retina. This is in fact deliberate, because it is important for us to see the finest details in the centre of our vision, and less so in the corner of our eyes. One well-recognised disorder that disrupts this mechanism is age-related macular degeneration, or ARMD. Though lifestyle choices and heredity both play a role, its appearance is largely a condition of ageing. Over time, harmful deposits of a substance called drusen build up like sediment within the retina, damaging cone cells and rendering that central region of vision completely blind to incoming light.

Part 4: Rods and cones are far from the only cells in the retina. Once activated by light, they release neurotransmitter molecules onto neighbouring cells that now truly begin to process the visual information that the eye has just detected. They are called bipolar cells and horizontal cells, and this, in many ways, is where the magic happens. This is where specific patterns of light across space and time start to be decoded into the building blocks of an image.

As you can imagine, the positioning of the cells involved in this transformation is crucial. Bipolar and horizontal cells are positioned beneath the rods and cones, and since there are considerably more rods and cones than bipolar and horizontal cells, visual information is effectively funnelled down a channel that this unique spatial arrangement creates. This now allows us to introduce a key concept in the neurobiology of vision, which is the receptive field. To better understand this, we will for a moment leave the realm of sight and think about this using the sensation of sound.

Imagine you’re at a classical music concert. You notice that hanging above the orchestra and dotted around are several microphones, and while you in the audience hear the music collectively all at once, each individual microphone can only detect the sound from its own small patch of space. The microphone above the violins, for example, picks up the sound from the violins only and not from the percussion at the back of the concert hall. In the nervous system, a receptive field is akin to this patch: it is the specific area in the sensory world that affects the activity of any given neurone. Now also imagine that the microphones are tuned in only to one frequency – in other words, they can only detect sound from one instrument, and if the microphone is placed above a different instrument – say, drums instead of violins – nothing will be picked up. Neurones in the retina with their respective receptive fields work in exactly the same way. Just like the microphones with their special patches are distributed above the orchestra, neurones with their special receptive fields are distributed around the back of the eye. When the type of visual information in the surrounding world matches the receptive field of a neurone, it becomes stimulated – via the retinal-rhodopsin route that we discussed earlier – and it relays this to neurones that connect to specific regions of the brain involved in the final stages of processing visual information. That in itself is an entirely separate and rather long story, so it’s best we save that for another time. Meanwhile, this is where our journey through the visual system comes to an end. We have seen what happens to rod and cone cells when they interact with light, and how they relay this message to their bipolar and horizontal cell neighbours. We have, of course, only scratched the surface of this astonishingly complex system – so to learn in more detail about the workings of the human brain and nervous system, listen out for more on CortexCast.

So, it’s goodbye from me until the next episode. All the best!