Video 2: Seeing -- Color

[00:00:00]

Bevil Conway: Thanks very much for the invitation to come and speak today. It's really fun to be on this panel and I'm glad that my Mum didn't take me out of the candy shop and let me pick as much candy as I wanted. It's especially fun to be here with artists whom I have such terrific respect for. And I wanted to say at the outset that one of the often implicit, it's taken to be an implicit goal of science is to demystify the magic of our experiences of the world, and I just want to lay it to rest, that that is not at all my goal.

I'm interested in that magic of perception, and that's in fact what got me into the business of neuroscience to start with. And if an analogy helps, it's like a wine maker who becomes more and more in love with wine making the more and more they know about it, because the more they know about it, the more mysterious it becomes. And for me, that's very much my obsession and fascination with color.

I'm looking forward to hopefully a much longer discussion with Tauba at the end, and then into the future, about the ways in which from our different perspectives we can start to gain traction on what this problem might mean and enrich mutually our understanding of it. I'm looking forward to your questions, too.

From a neuroscientific point of view, the reason I like color so much is that it's a very powerful tool for understanding how we take in information, process it and produce some thought or action. And this is something that I think we often take for granted. Famously at this institution, David Mars said, you know, to some graduate students, “I want you to spend the summer and we now know how the visual system works, because we figured out what the spectral sensitivities of the cones are, and Hubel-Wiesel have shown us how primary visual cortex works, so go and make a machine that does it.”

And the graduate students went away and then they came back a summer later and said, “Well, it turns out it's kind of more complicated than that, and our machine can't even recognize, like a hand.”

The story reveals the great computational challenge that we face in trying, that the visual system faces, and moreover it's the challenge we face in trying to unpack it. So the problem is that we're all endowed with this thing that enables us to see and experience the world. And then we have to try and use this thing, this nervous system to figure itself out.

And it's what Nancy Kanwisher describes the non-problem of the tow truck towing the tow truck. It's not really a problem; it's just difficult, because we take it for granted. We take for granted the fact that this thing works so effortlessly.

If I asked my nephew how you see, he says, “I open my eyes, dummy.” I mean, Uncle Bevil, that's not a problem. And color for me is the epitome of this challenge within vision, and I think you've started to get a sense of why, of where that comes from.

When we think of color we think of red, green, blue, yellow, and maybe a few others, and somehow it's as if these things are so perfectly endowed that we're all effortlessly able to see them, that those things must be out there in the world. And this really is the challenge that neuroscience faces, which is to understand that your ability to make that assignment so effortless, to see color so effortlessly, belies an enormously sophisticated neural machine that makes that possible.

The fact that you can say, “Oh that's red,” it must be really easy, that, that difficulty is what has led philosophers and scientists to ascribe redness to something out there, as opposed to something that's computed in here.

That's the sort of background about why I study color, because it's a really fabulous system for understanding how you transform these peripheral, under-determined signals into something of behavioral relevance. Today I'd like to talk about, to take up two questions, which is first, that big question I laid out, which is: What is, what is the computational goal of color? What is color for? You know, we've heard a few little tidbits here and there.

Caroline mentioned at the beginning some ideas and I'd like to pick them up. And then, the second part, I'd like to talk a little bit about how these goals are implemented in the brain, which is, I might get a chance to talk a bit about some of my research.

It turns out that for most objects, color is not at all useful for recognizing objects. In this graph it's showing the reaction times for recognizing line drawings versus colored photographs. And it turns out, actually you're a little bit quicker recognizing line drawings.

So your initial impulse – that I had at least – is debunked, that color helps in recognizing objects. It might be true for certain kinds of objects, but we'll get there. It turns out that for most objects, if you remove all of the value information, that is, the black-and-white information that you might encode in a black-and-white photograph and just have color, that pure color information is insufficient. It's neither necessary nor sufficient for you to be able to recognize many kinds of objects.

And in this case it's a face, and the face is of my friend and mentor David Hubel. And it's for this reason, I think, that many vision scientists have steered clear of color,

[00:05:28] because it doesn't look like you need color, really, to do anything. It's like, well, it's sort of an add-on. That's where I'm trying to change the field a little bit, but it's an uphill battle. Color is used to recognize some kinds of objects; it can be useful under very degraded image conditions.

For example, in this situation, as shown by Pawan Sinha and his colleagues, to see, for example, the boundaries between the hair and the face in a very blurry photograph. This is Lady Diana, and those color cues help you segment her face, and they do so, even under degraded, especially under degraded image conditions, but here the color is irrelevant, as shown in the false colored image on the far right.

Okay, but this seems like, why did the visual system go to all this trouble to give you color to do this thing? When I read this paper as this is the best evidence we have today for why we have color, I thought, that seems to miss the point.

And here I will just footnote all of what Tauba talked about, which is, when you experience the world, color is a lot of stuff. You really like it. We spend a lot of money buying color TV's. We spend a lot of money buying Tauba's paintings, because they move us. There's nothing in them, it's like colored spray paint. I mean, really? So it's doing something else. And this is really the piece that I'm trying to bring to the neuroscientific community, which is to take seriously the fact that color is doing something that we haven't been very good at quantifying, at figuring out.

And I'm not going to tell you that we have an answer. I'm just saying my guess is that there's something down that road and we probably need to keep poking around to get there. I think this image does give us some clues.

So Sinha and his colleagues don't talk about it, but if you look at the image on the far right that false color image, I don't know, when I first looked at this, she seems a little sick. Doesn't she seem a little ill? And that feeling, like it hits you right in your gut right away. We were like, um, something's not right about that picture. And it's almost pre-verbal, I couldn't figure out whether where this information came from until I went to sleep and woke up the next day and I was like, it's because it's false colored. It looks like really weird.

And this, of course, feeds into the use of color filters on your Instagram account, where you want to have a particular kind of image quality, because it's got a really deep emotional impact on you, and in particular, color as a metric is often diagnostic for certain kinds of changes in health status.

So first aid people are trained to look at complexion changes because they can tell you with high immediacy whether or not someone is sick or not. And indeed it turns out that, for certain objects for which color is diagnostic, if you change the color, you delay the reaction time.

So I think now we’re starting to see that color isn't really a tool for recognizing generic objects. It's for recognizing objects for which color is behaviorally relevant. And now I think we’re going to start to get some traction on the problem.

Okay, so that reaction time argument is supported by another attribute of color, which is that color facilitates object pop-out or object recognition. To be able to discriminate the two’s in this image is much easier when they're colored when than they're not this is well known in visual psycho physics. It's exploited all the time, and the people who are using this as a tool to train their animals or their subjects spend very little time figuring out why this works, like why does color work so well as pop-out? And I think we're starting to see how they could come together.

Okay, so the point that I'd like to make for the first part of the talk, about what is the computational goal of color, really is boiled down to two pieces. One is color might be useful for segmenting objects, that is, for discriminating where those boundaries happen so that you can identify an object's shape. That's a pretty time-consuming task and color looks like it could provide some help in doing that.

But more critically I think, is that color helps facilitate the rapid detection of behaviorally relevant objects, and I think it's that evolutionary incentive, if you will, that makes and confers on color this thing that we all experience, which is why you're here. You like it; you're interested in it. This is evidence of some kind of selective pressure.

So to just hammer home how these two things could work we've got segmentation cues, for which the color is not important, and then surface properties, for which color is important. And I like this idea because it takes seriously this idea that color could be a reward. And, in fact, there's evidence in the industry that color-emotion associations are highly trainable, and we exploit them and the various industries exploit them all the time.

Artists of course exploited this too, to be able to liberate from the representation of shape, color to do a wild and wildly different sorts of things. So here it isn't being used to encode shape information, but to do a bunch of other stuff.

[00:10:54] So what is color for? Well I think it helps in facilitating object recognition, but it also serves a whole host of functions that touch on many aspects of perception and cognition, including things like emotion, reward, and for those of you that have little girls, I have a daughter who's three years old, she's obsessed with pink; that happened relatively recently. I think it's even a very important cue for social cognition.

Tauba talked a little bit about the three cone types. There they are at the top. The first surprise about color vision was that these three cone types don't actually predict red, green and blue. In fact, their peak spectral sensitivity of the so-called red curve is sitting over the green. In order to see long wavelength light as red, you have to subtract two cone types in order to be able to discriminate long wavelength light as red. And this tells us right away that there's something very important in terms of the neural machinery that's supporting the extraction of color from those three cone types.

And because this is MIT, I feel like I can show some math. The beauty of studying color is that we can determine with very high precision from the spectral reflectance function of an object, the relative cone activations of every single scene, just by taking the dot product of that spectral omission function and the three cone type absorption spectra.

The problem is that that doesn't tell you what color something is. And if there's any doubt in that I want you to take out the red green color filters and look through the red filter and look at, no cheating.

So look through the red filter, no cheating. Okay? Absolutely no cheating. I want you to tell me, what is the color of the garment of the woman at the window? White, white, gray. Okay, take away the color filter and it is, of course, red. Okay so what's striking about this, this is the Paradox of Monge. It's been around for hundreds of years. That red is unaffected by the color filter. The light has already been filtered by the paint, as it were, to extract everything but long wavelength energy.

So the long wavelength energy that's going through your red filter with and without the color filter is exactly unchanged. What this tells you is that your perception of color is actually contingent on a whole host of operations that you take completely for granted, and these operations have to do with the spectral and spatial temporal chromatic context in which this image is seen. A simple way of characterizing this would be as a chromatic opponent mechanism, in which that thing is seen as red because the background is decidedly not red.

So here, your assignment of an object's color is contingent on an implicit calculation that your visual system is making about its relative redness in a given context. And for artists this isn't a surprise. The reddest thing then would be a red thing on a green or a bluish green background. But from a neuroscientific point of view, what this tells us is that red is a computation made by the brain as it attempts to come up with a label that is stable against space and time.

And I like this sort of from a poetic point of view as the counterpart to Tauba's argument about how time is implicitly involving the changes of three dimensions. Here actually, the goal of color seems to be to actually hold the thing steady to protect it against the changes that seem to be inevitable.

So how does the brain do that? I don't have too much time to go into it. Suffice to say that my colleagues and I spent about ten years looking at the neural mechanisms for spatial-color contrast and discovered in primary visual cortex that there are neurons that are capable of performing exactly the operation that is required. Importantly, these mechanisms happen in your cerebral cortex, not in your retina.

So we already have evidence that the calculation of color, your perception of color is contingent on something downstream of what's happening in the retina.

[00:15:05] So the next time someone tells you that color is a retinal thing, you say, "Nuh-uh." Color is a cortical thing, that is, the interpretation of signals received by the brain in the cortex. One of the surprising things that our results revealed is over what small a spatial scale these chromatic interactions take place; the extent from the science shows us that it's on the order of half a degree, if not less.

What that means is in great demonstrations like this, pictures like this where Josef Albers has painted with a single color stripe, a stripe to appear two different colors, his genius was in the clever interplay of the backgrounds to have that stripe appear two different colors. That comes about because of the very local unconscious interaction between this stripe and the immediate background. And to test that idea we could simply get rid of that interaction with a white buffer, and it turns out that you can recover a stable percept of the stripe just by doing so.

When I was a Radcliffe Fellow I had an opportunity to look at the works of some great painters, included amongst them is Matisse, and I was delighted to discover that he does the same thing. You might ask, why is he doing this? Did he just run out of paint? I think everybody, he was a rich man; he had lots of paint. I think he could've finished it if he'd wanted. He's doing this because this is

protecting the color of the marks against these color contrast changes that are introduced every time you put one color next to another. Okay, these changes can be really dramatic.

Here, let's have audience participation. What are these colors?

Great. So this is an image from, from Beau Lotto. It turns out that physically that patch is identical to that patch, and we know it's so because you can just eclipse the background, and it turns out, in both those cases, it's gray. So, you can see why painting his color is traumatic because if you set out to paint this cube to start with, you would naturally start by mixing, blue paint for what looks like the blue square and yellow paint for what looks like the yellow square. Blue there and yellow there, but in fact you would be wrong.

This is, I think, why things like paint-by-number kits are so much fun, because you're instructed to paint this thing in the sky, and then over the course of the painting, as if by some sort of visual joke, that thing turns out to look right. Whereas at the beginning, you're like, the sky's black. That doesn't make any sense.

In the last few minutes I want to turn to some science from my lab and others just to start to get a handle on how it is that we do all of these other things. So color is one little piece, but I think actually it's not a big enough term.

As we discover more and more things that color is for, we're going to become more and more in need of a bigger arsenal of ways of talking about it and thinking about it. And I think we're just at the beginning stages of doing that. So downstream of what's called primary visual cortex – this extra stripe part of the brain – this is a huge chunk of the cerebral cortex, and it turns out that a lot of it is involved in color.

These are just patches of brain that show greater MRI activation to color versus black/white, and if we record the activity of single neurons within one of these little blobs, each blob has hundreds of thousands of neurons, this is the response pattern for one such cell and for another cell here.

And to summarize all of the neurophysiology, both these cells respond optimally to green and they happen to sit right next to each other. We discovered that if we record many of these cells next to each other, the cells neighboring each other have a

[00:19:09] sequential progression in their color preferences, going from in this case, a kind of yellow through red – that's an outlier – red, bluish red and purple, and this provided the first evidence for little micro-organization of the chromatopic map. One of the goals of my lab which sort of comes full symmetry with some of the questions that Tauba is asking is this idea of how color is organized doesn't seem to be out there in the physical world; it seems to be actually the way in which that physical world is implemented in the brain. And maybe we can reverse engineer our model of how color is represented by looking at the organization of color circuits in the brain.

In the last few seconds I want to just talk about what's happening down here, so all that I talked about, those little color maps, are all back here in the brain. There's primary visual cortex. This represents progressively more advanced stages of processing, and you can see there're lots of parts of the brain here that are involved in color.

I was very struck by this sort of inhomogeneity down the temporal lobe, and we decided to map in the same, these are actually in monkeys, but it turns out to be the same in humans. The responses to faces, and they provide a very nice functional landmark, and you can see actually the face maps. This is in a sagittal view where the eyes would be looking to that direction. You can see that the faces form a parallel separate track for colors, which provides very nice evidence that in support of this, one of the original observations I showed you today, that color information is not used to do things like face processing.

Like we've got different circuits that are doing that, and we’ve spent as a vision community a lot of time looking at these circuits, and what these results reveal is there's a whole lot of brain that's involved in color. Maybe we should spend some time thinking about what that part of brain is doing, and we might come closer to understanding a little bit about what supports all of this interest in color. And with that I'd like to thank you for your time.

Alma Steingart: In exhaustion or in frustration, or just to refresh eyes, strained from being trained too long on my computer screen, I shut them and rub my palms again, against my closed eyelids. A psychedelic swill and burst of cardinal, celadon and ochre projects itself on the cinema screen of my visual cortex. Such cross-modal crossing of signals in which

[00:22:30] haptic and visual sensory inputs gets crossed is a sort of an halucinatory spectacle that led Goethe to posit the corporal subjectivity that made a clean cut with Newtonian optics. Seeing color was no longer a privileged form of knowledge, but also an inquiry into an embodied experiment of, and the intermixing of, sensory organs and sensation.

We carry the weight of such romanticism when we think of colors as mere variables and an aid to understanding mathematics, and the history of mathematical knowledge and its relation to manifestly embody sensory practice is what I think and write about. That is, there’s nothing specific to color when it appears in mathematical problems and theorem. It is merely one factor, an entirely arbitrary one, by which a mathematician can mark some sort of difference. But does it?

Color might be arbitrary, yet its regular appearance in mathematics as a way of assigning variables suggests precisely that its role is not random. In 1957, at the height of mathematical formalization, Vannevar Bush, initiator of the Manhattan Project and champion of the National Science Foundation, sent a letter to mathematician Solomon Golomb. Golomb recently published a short column in *Scientific American*, reporting on a proof that the particular carving of checkboard with pieces of a particular shape was impossible.

The proof was arrived at by coloring each tile on the board. Bush naively asked Golomb whether the proof still holds if the board hasn't been colored. Golomb laughed at Bush's question, wondering how such a powerful champion of science could know so little as to think that color mattered to mathematics. A mathematician makes a similar joke. This time at an historian's expense. One evening a mathematician and an historian amble across campus in the waning light, discussing the four-color map theorem.

So the gist of the theorem is that for any possible map, one needs no more than four-colors so that any two countries sharing a border, uh, have different colors. The butt of the joke is the historian who responded, “Oh yeah, blue, yellow, pink and green, isn't it?” So imagine the resounding and deprecating laughter of the mathematicians here. Of course, the colors themselves are immaterial; what matters is the formal notion of mapping as sort of cartographic distance. Isn't it? So let me quiet the raucous laughter of this mathematician with another sort of story about mathematics and color.

Diagnosed with incurable and inoperable and metastatic cancer, Ludwig Wittgenstein traveled to Vienna, where he began thinking about color. He reported that his impending death cleared his head, and that for the first time in years he felt once again able to do philosophy. Wittgenstein's abiding interest in color dates,

[00:25:51] as noted earlier, to his earlier work, in which he elucidated both the notion of color space and their color exclusion problems, which I wouldn't dare delve into today, but in his final days, his thinking changed significantly, and after his death a sheaf of paper simply titled ,“Remarks on Color” was discovered on top of his desk in Cambridge University.

This is not it, this is just some artist’s working off the book. Wittgenstein's right, that these remarks are neither about color as simply psychology or phenomenology, but instead, “Here we have a sort of mathematics of color.” What he meant was that rather than being something to be classified and ordered by mathematics, or a handy representational tool for making variables in mathematics, the bond between math and color was much deeper. Indeed, they might be thought of as models for one another, perhaps more broadly, they are both models for how we know what we know.

They're both, to use his language, ‘language games,” and as such, description of a proof of a color is always by necessity insufficient. “Can one describe higher mathematics to someone without thereby teaching it to him? To describe the game of tennis to someone is not to teach it to him, and vice versa. On the other hand, someone who didn't know what tennis is, and learns how to play then knows what it is.”

So to paraphrase, no one can describe the color blue to a colorblind person, and like tennis, in order to know what math is, one must learn how to play. So to extend this thinking one step further, despite the seeming failure of an inter-subjective grasp of what we mean by color, or by mathematical object, we treat such categories as natural ones, that precedes our own experience of them – our own attempts to tenuously grasp at a private understanding of, say, transfinite numbers or cerulean blue, precisely because such language has already been appended to them. The terminological identity may stabilize this concept as [inaudible 00:28:16] but they are woefully insufficient, adjusting to an experience of them. So, returning to Wittgenstein's language, “Words can merely characterize the impression of a surface over which our glance wonders.”

This is not a theory of color, à la Goethe, nor a logic of color, any more than it is about a psychology of perception. It is rather, as Wittgenstein says, a mathematics of color. It speaks equally to the color of mathematics.

So let me fast-forward fifty years, to another dead philosopher of color, David Foster Wallace. In 2001, Wallace published a short piece on Wittgenstein, which later appeared in his essay collection, *Consider the Lobster*. Lowering the tone somewhat,

[00:29:06] Wallace wrote “The Teenage Stoner.” Now I'm going to quote this passage in its entirely, because I think it's worth it:

“Eating Chips Ahoy! And staring very intently at the television's network PGA event, for instance, the adolescent pot smoker is struck by the ghastly possibility that, for example, what he sees as the color green, and what other people call ‘the color green’ may in fact not be the same color experience at all. The fact that both he and someone else call Pebble Beach ‘fairways green,’ and stoplight’s ‘GO signal green’ appears to guarantee only that there is a similar consistency in their color experience of fairways and GO lights, not that the actual subjective quality of this color experience is the same; it could be that what the adolescent pot-smoker experiences as green, everyone else experience as blue. And what we mean by the word *blue* is what he means by *green*, et cetera, et cetera, until the whole line of thinking gets so vexed and exhausting that the adolescent pot-smoker ends up slumped, crumb-strewn and paralyzed in his chair.”

But rather than succumbing to such crumb-strewn solipsism, the philosophy dropout Wallace resurrects the specter of the dying Wittgenstein to argue precisely the opposite – that language is always built on consensus, and thus can never be private, apolitical or lacking in ideology. This is true of pain, of color blue, and of notably, transfinite numbers, too.

But I've gone on ahead of myself. Allow me then to circle back to question how the colors of mathematics pertain to space and its higher dimensions.

Let us begin with the little paradox Poincaré asks us in 1905. Beings, whose minds were made as ours, and with senses like ours, but without any preliminary education, might receive from a suitably chosen external world, impressions which would lead them to construct the geometry other than that of Euclid, and to localize the phenomena of this external world, in a non-Euclidean space, or even a space of four dimension.

Elementary and conventionalist, Poincaré sought to dispense with both the experimentalistic, experientalist, and an apiary conception of space.

Can we imagine four-dimensional space, Poincaré inquired. And he was quick to respond that yes, indeed, we can. Instead of imagining beings inhabiting four- dimensional space, Poincaré asked that instead we imagine ourselves with slightly altered visions, “To a red sensation affecting the same point of the retina will be regarded as identical, only if they’re accompanied by the same sensation of convergence and also by the same sensation of effort of accommodation.”

[00:32:09] But what if experience has taught us otherwise? What if the sensation of accommodation and the sensation of convergence by which we see three dimensions, do not supplement one another? Then, to a visual sensation of red would be distinguished, in “the whole visual space would have four dimensions.”

So this third experiment leads Poincaré to suggest that, “it suffices to fit over the eyes glasses of suitable construction to make space of four dimensions.” Tauba that might answer your earlier question of what we need to do.

Whereas Poincaré’s investigation into the fourth dimension questioned the relation of mathematicians' geometrical space to their perceptual space, some of his contemporaries thought to actively bring the two together. So, to come full circle back to the way Caroline ended her talk, I'm going back to Charles Hinton, coiner of the word ‘tesseract,’ who was perhaps the greatest popularizer of the fourth dimension at the turn of the century. He believed that investigating higher dimensions would lead to an understanding of a higher being than ours. Hinton wrote profusely on the fourth dimension. “With knowledge of higher space, “he mused, “that come into our ken boundless possibilities. All those things may be real, whereof saints and philosophers have dreamt.”

To do so, he constructed a colorful model of cubes, in hopes of teaching his fellow men how to perceive higher dimensions. And I want to read some of his instructions to give you an idea of how they went.

“The square vermilion traces a pale-green cube, and ends in an Indian-red square,” for example another one.

In this square he has two lines, which he had before. The blue line with gold and buff points, the deep yellow line with light blue and red points.

Or finally, the black square traces a brick red cube.

So, if you feel confused, you're not alone. When Martin Gardner years later mentioned Hinton in one of his *Scientific American* columns, a worried reader responded, “A shudder ran down my spine when I read your reference to Hinton's cube. I nearly got hooked on them myself in the 1920s. Please believe me when I say that they are completely mind destroying.”

And since I've already mentioned David Foster Wallace, let me invoke him one last time, as he, too, noted the destructive power of thinking about the fourth dimension. “There is something I know, which is that special dimension beyond the Big 3 exists. I can even construct the tesseract or a hypercube out of cardboard. I know all of this, just as you probably do. But now, try to really picture it. Concretely. You can feel, almost immediately, a strain, at the very root of yourself. The first popped threads of a mind starting to give in at the seams."

So now, we arrive with an account of mathematics and of color, that are mutually reliant on one another, and more so, of the intensely social act of experience, the insufficient, yet wholly necessary work of description, and the socially enabled, yet sometimes lonely experience of learning how to proof, to play tennis, and how to see in a trained and careful manner. Thank you.

[00:36:22] **Question & Answer**

Caroline Jones: We are now going to sit up here and we are going to take some questions or some answers. Maybe that's where we should begin. So just sit where you like. And here's where I peer through the stage lighting to see.

Audience: I was wondering if you could address a bit, especially since, art inspires mutual reaction, the relationship of colors with motion, or for that matter, where a spectrum of synesthesia comes in as color intersects with other senses.

Caroline Jones: Now I broke the rules because I was supposed to wait for him to get a microphone. But I'm going to repeat the question and then you'll know if I received your message correctly.

Audience: [Inaudible 00:37:15].

Caroline Jones: I heard three points. So one is, how artists capture a certain emotional intensity of color and could the panelists, you know, could the participants here think about that emotional valence, and then sliding into questions of synesthesia, where two different senses cross modalities.

Audience: But also, how, how is it that we react to color in an emotional way, and also, is that cross-cultural? Do all cultures react across . . .

Caroline Jones: Here's your microphone. So why is it that we react…

Audience: Why is it that we react to color in visceral ways, which is sometimes the intent of an artist.

Caroline Jones: Right.

Audience: Is there some relationship to their, that to some synesthetic reaction, and is the reaction to color cross-culturally the same or something we learn?

Caroline Jones: Oh. There are about 20 questions in there. That's great. So who wants to start with that one?

Tauba Auerbach: Seems like your area to start.

Bevil Conway: I'll launch in. You want me to move that direction? He's waving at me. I'm having a synesthetic experience.

Tauba Auerbach: What's happening?

Caroline Jones: Just plow ahead.

Bevil Conway: Just plow ahead. All right. Okay so question one. Why is it that we have, or how to we have a visceral or emotional reaction to color? Answer for me? I don't know. But there is some nice neurological evidence that speaks in support of this, a widely reported anecdote. For example, patients who suffer an acquired cerebral achromatotopsia, that is a color blindness associated with damage to the cortex, attendant to that is often a depression, which is not true in other, in many other kinds of acquired perceptual deficits.

So people who lose, for example, the ability to see faces don't go around bemoaning the fact they can't see faces. They just can't see faces. People who lose the ability to see motion. You know, they probably shouldn't drive a car. They have difficulty pouring cups of tea but they don't go around being depressed and unhappy. So there is some organic basis, I think, for this assertion. There's some lovely work from Helen Mayberg's group, who used deep brain stimulation in intractable depressed patients, in whom she had identified particular brain areas that it were either hyper- or hypoactive compared to normal.

[00:39:54] The logic here was a kind of micro scale of electroconvulsive therapy, and it's done in the awake patient in the OR and strikingly and surprisingly one of the things these patients reported was a partial alleviation of their depression but an intensification of the colors. It's a footnote in a neuron paper. I can send it to you if you're interested. No one knows what to make of it, except that yes, the answer does seem to be that there is some connection between the experience that you have of being viscerally moved by color and the neural basis.

Caroline Jones: Color my world.

Bevil Conway: Color your world. And I'll let off the stage to someone to talk about the other questions.

Tauba Auerbach: I mean, I can't really address with any authority the cultural question, but I would guess that the answer is yes, because I've experienced my relationship to different colors change and different color combinations specifically to change over the course of my life, so that tells me that it's a really, it's a plastic kind of taste.

Caroline Jones: And it's associational.

Tauba Auerbach: Yeah.

Caroline Jones: So historically pink was considered way too strong for girls, in Belgium in 1920. So the current pinkification of femaleness is a very contemporary phenomenon, and not, you know, it's not hardwired.

Bevil Conway: And one way I think people have tried to attack the question is to say, "Well, maybe it isn't the specific color association but maybe it's something second-order about the valence of that emotion." So, it is true cross-culturally that red is a pretty important thing and you have some evidence, you know, from your experience, red is used for passion and love. It's also STOP signs, it's also anger, so it's not the direction of the sign positive or negative, but maybe the arrow length that this is a powerful thing, and there's some evidence that cross-culturally that is preserved.

Caroline Jones: And so there was the final piece about synesthesia and I'll just deliver it.

Bevil Conway: Oh, yes. She knows all about synesthesia.

[00:42:04]

Caroline Jones: I don't know about synesthesia, but I'll deliver some findings from a conference that I attended in which certain neuroscientists are theorizing that we are all synesthetes when we are born and that part of the cross modality is kind of pruned with synaptic printing which a very important stage of human development.

Some theorize that synesthetes are regressed, which is a very contentious position, but that they have failed to develop this pruning in a certain sense. So it's fair game for many, many theories. And what I find interesting, as an art historian, is when it was the most cool to be a synesthete.

[Audience laughter]

Caroline Jones: So someone like Kandinsky probably wasn't, but deeply wanted to be, and that is interesting. When these sensory confusions are themselves deeply desired, I think has some cultural information and it's a lot of fun. And of course reading… [Crosstalk 00:43:02]. Sorry.

Tauba Auerbach: I would be tortured to be a synesthete, like in a true sense of the word, to have these… It would be just like being bombarded with so many stimuli.

Caroline Jones: But think about the fact that synesthesia, roughly speaking, is historically identified as a pathology when literat-, when literacy is extended to the most people. In other words, reading isn't for synesthesia, you're looking at a strange abstract black shape on a white background and you're being told, "Mama." In other words, that this should stimulate in your mind a sound.

Right? So the fact that it's identified as a pathology at the very moment the people are being asked to read and that the most common pattern of synesthesia is a cross modal. I see this letter and it's red or I see this number and it's crying. You know I mean this visual [inaudible 00:43:59] crossing is just… It's just very suggestive. I don't think you know, they've done enough work on it, but it's, it's a very interesting nexus of cultural, technological and brain phenomena.

Bevil Conway: Germane to this discussion is that 90% of synesthesia, synesthetes have a, a confusion with color and something else. So you could conceivably have, you know, touch, and hearing and they sort of exist sometimes, but most of them it involves color.

Caroline Jones: Right.

Bevil Conway: Are we allowed to ask each other questions or is that…

[00:44:32]

Caroline Jones: Sure I'm wondering are there other questions coming from the multipurpose, from the outside rooms? No. not yet. Let's do one question that you have for the panel, and then I'll go to David's question over here. Did you…

Bevil Conway: Oh, yeah, I have a question. I think what's interesting is this argument and I want to hear whether or not you think it's valid from an art historical point of view because I've no way of evaluating it. Which is that the desire to be a synesthete came at the same time that there was this crisis in what constituted good art, and this provided a kind of scientific basis or a scientific way of, of saying you were better. Your art was better than someone else's art. And if that's true I think it's interesting because it seems to be relevant today with this proliferation of of an art market and where like I don't know what's good art. Do you know it's good art? I mean Tauba, what's good art?

Caroline Jones: Just ask me, I'll tell you.

Bevil Conway: What's good art? It's like, I don't know.

Caroline Jones: I think… You know, I mean, the historical question of when synesthesia becomes attractive, is super interesting and has lots of different parameters that we'd have to untangle. But certainly the position of modernism as something that wanted to radically question the stability of perception, the location of perception, the purpose of art. All of those things were being questioned.

Now the fact that in the case of Kandinsky, his first synesthesia experiences with Wagner and then his second major synesthesia experiences with Schoenberg. You know, suggests that he's not precisely trying to validate what he is doing through these comparisons. He's actually feeling a change in music through color, if that makes any sense. So he's using color in a way to model his own experience in music, and that, maybe there's a sense there of transferring values from one domain to another

Caroline Jones: Um, so David.

David Kaiser: I do have a question for Tauba about modeling of four dimensional space, but in relation to color and so I'm interested in whether you have experimented with or maybe it's more of the speculation about how color, not necessarily how it works, but maybe how it is in some way systematic within a four, a 4D space because you have been showing us 4D space and you were also showing us a lot of different 3D color models, and so I'm just starting to grasp the possibility of color being distributed, in 4D space and I'm wondering if your work has gone in that direction

Alma Steingart: When we first talked about me coming here, we talked about me trying to like model a proposal for a four dimensional color space. But I abandoned that idea for number of reasons. First of all that, that fourth access would not be terribly different than they would be sort of I guess yellowish, if I was going to use the tetra chromat as a starting point, the human tetrachromat. I also thought that four wasn't enough, because that's still starting with that purely retinal tri-stimulus model and as Bevil said so much better than I said in my talk, that really doesn't account for so much of what happens after the retina.

So, I really think we would need this like Albers model that has every color next to every single other color and I have no idea how to do that, so I decided to go in a more like reductive direction towards the weaving, which was my gesture towards that.

Caroline Jones: Thank you. Can we get the mic, to the man whose shirt is striped?

Audience: This, this, my question is for Bevil. You seem to be interested in the fact that or focusing on the fact that color was related to the texture and the thingness of things that, and I find that really interesting, and I want to make one observation and then a question. I guess I put it that way. A few years ago. I had done some work looking at how many colors do you need, and I'd taken I don't know, quite a few hundred pictures and converted them to color space and then done a cluster analysis. And you could do really a pretty good job with 24, so your box of Crayola crayons, if you pick them correctly, does a pretty good job.

Bevil Conway: Of capturing what?

Audience: Of representing the colors in the real world. There are not very many colors in the real world and, and I find that really interesting from an evolutionary point of view as to how the brain evolves. Okay second part of it is because of the thingness of things. Children with cerebral palsy have no motor control to be able to identify things. Have you ever looked at how, with functional MRI, what goes on in the visual cortex with people who have, who are, have physical motor skills problems?

Bevil Conway: I mean, the short answer is no. I think your observation about 24 colors as a basis is fascinating. I mean, there are people here actually who will be speaking tomorrow. Josh Tannenbaum is one of them that has some very nice thoughts on how it

[00:50:36] is that we as a developing brain, you know, having a developing brain build that brain to acquire and develop new knowledge which requires building a new concept. And I think of colors, the acquisition of a new color term to your vocabulary as that process embodied in a very concrete way so that you've arrived at 24. I think it's fairly enlightened and advanced…

I would say most cultures actually have a much more limited set in which maybe only three or four are necessary to capture all of the space. And I've been working in collaboration with Ted Gibson here at MIT with a, an ancient population in the Amazon Basin who seem to use color in a way that's much more primitive in some sense, but captures in its heart what it is that I think you started with, which is we use color to identify surfaces, like it isn't a great chance that orange, the color is the fruit. And that emerald is the color of emeralds and that, and you can go through a whole battery of your favorite color terms, and there's a surface that is, you know, rust. It's rust. I think from my point of view, that's interesting, 'cause it tells us something about what we use color for, what the problem is that the visual system is trying to solve.

But the difficulty is, how do you get at how you turn what are retinal signals, which have nothing to do with rust or any of these color category boundaries into something that is this discrete category. This discrete concept. And we right now have very little idea how to do that, or think about it.

Caroline Jones: And I would just add that there's a beautiful book by John Gage called, *Color and Culture,* and he writes about the Greek color naming system, which at first was terribly confusing to the translators because Hector was being dragged through Troy by his blue hair. Right? And Gage talks about how the Greeks actually had terms for luminance that were not connected to what we would think of is chroma. Okay? So Hector's kianos [PH] was lustrous, dark, almost iridescent. So if you think about a comic book the way it shows a black haired person with this blue highlight. Right? That was Hector's hair.

So kianos meant 'lustrous.' Chloris [PH] didn't mean 'green,' it meant fresh, moist, like plants. You know, and on and on. So the turn to a, a primitive culture or an ancient culture for me simply reveals the proliferation of fantastic difference in humans' valuation…

Bevil Conway: Right, right, right.

Caroline Jones: …of these experiences.

Bevil Conway: Right, right.

Caroline Jones: So what we have is, is a certain equipment.

Bevil Conway: Right.

Caroline Jones: And then we have neural plasticity and then we have the world that those were evolved to meet, and then the fun begins. That's my humble opinion.

Bevil Conway: I don't really like the term 'primitive' 'cause they're doing something really sophisticated. It's just different from what we're doing and it's our challenge to try and figure out, uh, using that contrast to figure out, well what are the universal goals of the system and then how are they deployable in different ways in different contexts.

Caroline Jones: Did you have something to add? Okay. I want to make sure I'm looking to the sides of the room. Gentleman in the hat, it's advantageous to have these colorful and/or patterned accoutrements.

Audience: Yes. I'm going to talk about the fovea or ask you rather about the fovea, but mainly I want to talk about, or get you to respond to, perhaps, the concept that the brain many times doesn't see what the eye sees, optically, and, and many times what the eye sees optically, isn't seen by the brain.

So a simple one is if you hold out your hand then your thumbnail is about the size of the fovea, and you can show that the foveas were all high resolution stuff is, by holding it up, say, to a *New York Times*, and you'd see that only the letters by your thumb are in focus, and the others aren't. But that doesn't work with color, and right now I'm looking at you, and everything in my periphery is color. And yet we know that the cones completely fall off in a periphery that's just supposed to be just the red rods, sensitive rods. So, what's the thinking that's going on now, that the image coming into the retina is not always what we see, and what comes into the retina, but often we don't see, as in many many experiments have shown?

Bevil Conway: I want Tauba to take it, because she talked… She talked us through that example about your peripheral vision.

Tauba Auerbach: I can't answer that.

[00:55:23]

Bevil Conway: I'll take a stab at it. So it's often said that your color vision is worse than the periphery which I think is related to two things. Your color is worse in the periphery and your visual acuity is better at the fovea, which is why you have to move your eyes from one place to the other. The acuity difference is true. The color difference is actually contentious. So people have argued actually that if you scale objects with visual acuity, your color perception and the periphery is pretty darn good.

So in order to have that *New York Times* be legible in the periphery you have to make the letters really big. If you make them really big you got great color out there. The deeper question I think you're asking is about the way in which that visual information, think about one moment of light entering your eye, cast on the retina. That thing is used to keep busy tons and tons of neural tissue.

You know, it's like the optic nerve head is a millimeter and a half in diameter and we've got hundreds of millions of neurons who are kept occupied trying to figure out what's coming down that, that, that pike. There are lots of ways of addressing that question, not the least of which I think is that at a certain point, our experience of vision is not retinally based and you know this, because if I present you with an object, my head right now, that retinal image is very different than that retinal image and yet effortlessly, these things are both a hand. And in fact, they're both my hand.

So there's some transformation that’s taking place between a retinal basis that is what our eye provides our brain to start with, and what our brains then digest that to be. And it’s that sort of divide between what I call a retinal base schema and a cognitive base schema, where I think there's lots of very exciting work to be done, that gets at the heart of your question. And right now I don't think we have a very good idea about what that transformation is; people are struggling to think about it.

Tauba Auerbach: That's a way better answer than I would have given.

Caroline Jones: Hi. Yes.

Audience: Hi. I‘m curious to hear more about the Amazon tribe you're looking at. Are they able to distinguish between different colors and the words they have for it? Sorry, two points. Do you have any information about people with blind sight in their relation to color? And then also do you think the role of different the wavelengths in daylight, inform us about our circadian rhythms? And, and how it's different in the morning to the afternoon?

Bevil Conway: Maybe we should group questions.

Caroline Jones: I think, I think we should go back to Tauba's meditation exercise for this one, right? And get our circadian rhythms coordinated and humming together.

Tauba Auerbach: I don't really know about a color component to that but I did recently read about some cave experiments wherein people were deprived of daylight for months at a time and their rhythm stretched, universally stretched out, no one's got shorter, and a very common rhythm that people sank to was sort of a double time like a 48 hour sleep-wake cycle.

And Michel Siffre, I think I'm using his name right conducted this experiment on himself and he intended to be in a cave for two months, and he would call the surface and count out what he perceived to be second intervals, and he started counting slower and slower and slower and when his team came down to, to retrieve him after two months he thought one had passed. So, that doesn't say much about the color, but it does say something about the power of the light.

Bevil Conway: Maybe we can meet ‘cause you asked a lot of questions and a lot of the data are unpublished, so I feel like it's not worth talking about here. But can I ask Tauba a question? I have been dying to ask.

Caroline Jones: You have the power of the podium.

Bevil Conway: Okay. So I think one of the fascinating things is happening right in this sort of room is that you know we’re, we got facts, and we like dealing with facts and so you know that breeds kind of next fact. What's the next fact? What I find fascinating about making art is that you don't start with any facts or at least it doesn’t seem like you do. You sort of start with some facts but you actually end up in a way that in some ways is unpredictable from where you started.

It’s like you're given a set of things and then you end up over here, and that's the part that I'm like blown away by, and I would like to understand more about that process and what's happening and whether or not there are things that you learn that are strategies that get you able to do that to exploit the power of this perceptual cognitive apparatus to be able to take what seems to me a completely nonlinear route, from a set of starting propositions to an endpoint.

Tauba Auerbach: I'll do my best to answer that. Meditation is a part of cultivating that ability in myself. And I do feel like I start with facts. I'm interested in facts. I read about things but just translating that information into an object, a painting, a

[01:00:54] photograph is not terribly interesting. Something else has to kick in at some point in order for it to become, in my opinion, a worthwhile artwork.

I would just call that that kind of stomach thinking that happens in the foam and it's maybe like… I spend a lot of time just trying to cultivate that state of mind and I don't know if I have a, sort of a formula for how to do that, do that, 'cause it's changing all the time.

But I think that some kind of just purely visceral thinking has to kick in for me at some point and I found that I was particularly freed and able to and be able to do that when I started to work on those gold paintings and just go… Use a process by which I was going to paint and paint and paint at, at the end. I felt really free to just… I mean I throw this color next to this color and then see if that just feels right, like I'll know it when I see it, and then just trust that.

So when I started to work that way and um, the prolific producer and harsh editor. I found that that was more possible for myself.

Alma Steingart: Does this sort of question that you have when you start the work change as well?

Tauba Auerbach: Hmm?

Alma Steingart: The question that you have yourself when you start the processes ends up changing or that the question remains…

Tauba Auerbach: Yeah, I think it's always changing, though I'm not necessarily knowing that at the time.

Caroline Jones: I think it's interesting that both Alma and Tauba, without having read each other's papers, you know, went towards hypnagogic states and drug states, and there that discussion on that the, the humanists here all spoke about Wittgenstein and this fundamental existential question about whether my 'green' is your 'green' or my 'blue' becomes your [inaudible 01:03:02]. And at some level it's fascinating that color induces that question. We don't ask if your triangle is my triangle. We don't ask if your reading the alphabet is the same as my reading the alphabet. Right? We don't have these existential questions about that. So I think, um, if we want to remember that Tauba asked a question if anyone wanted to supply her with special kinds of drugs for color…

Tauba Auerbach: No, I want to make me a drug.

Caroline Jones: Like she wants make drugs. Uh, it would be interesting to think about whether we would voluntarily take a drug so that we could see the colors that our partner saw, for example.

Tauba Auerbach: Definitely.

Caroline Jones: I would, I would do that in a second. So…

Bevil Conway: But you have an interesting partner.

Caroline Jones: Well I do. But, uh, you my father was colorblind. I gave that to my son and yet, you know, I get to see those colors. Right? I think that we have identified is the existential and emotional mystery that we began with it's just tremendously exciting to see the work in all kinds of domains: philosophy, mathematics, art, neuroscience, that's you know, chipping away at that without back to your opening point, without diminishing the mystery, the joy and the emotional attachment we have to this, to this qualia. So I think we have time for one more question. Let's go to this side, which we haven't, we haven't heard from yet.

Audience: So I, I think my question ties to your comment. While I listened to everybody talk we heard three different ways of thinking of color. One is a fairly robust computational property. One as a language game, a property that emerges from a language game that might be tied to the computational property, but might be culturally inflected. And the other very different from a triangle as a simple and unanalyzable property of phenomenal experience, that can't be shared but can only be mentioned in some sort of way.

And I wondered if the speakers found any sort of friction between these three different ways that people were speaking about them or whether these all mesh together different levels of our behavior or something like that.

Bevil Conway: That's a terrific question.

Tauba Auerbach: I don't feel friction.

Bevil Conway: I feel friction.

[01:05:27]

Tauba Auerbach: Bevil needs to do more meditating.

Bevil Conway: Yeah, no, I feel lots of friction. I feel friction in lots of ways, and I would start by saying, I feel friction in the way in which we use language to mean very different things to different contexts. So I have to kind of give up something when I listen to Caroline talk about the way she thinks what I do. I mean, you know, and this isn't, this isn't an attack on Caroline. What this is is there's some limitation in what it is that I've thought about that I can communicate and that limitation seems to be almost a metaphor or metaphorized, by color itself.

It's like something about my ability to tell you something doesn't quite get across and with language we have this illusion that it seems to work, that I can tell you something and you're like, "Oh, yeah. I get it." And with color it's like, "Mmm. Oh. Mmm." Still stuck. And that's my friction, because we're all using these words and it's like, well that's not… I don't think that's what I… Is that what I meant? I don't know?

Tauba Auerbach: I guess I'm really interested in sort of where language drops off and things like color pick up so that doesn't, that's isn't an uncomfortable zone for me. And that…

Bevil Conway: You like those zones. You want to be at the interface.

Tauba Auerbach: Yeah. So I guess that explains why I don't feel as an uncomfortable, like mismatch or something.

Bevil Conway: I don't like sailing. Maybe that's.

[Audience laughs]

Bevil Conway: I don't like sailing. I don't like the water.

Caroline Jones: You don't like the frogs.

Bevil Conway: [Laughs] I don't like the frogs.

Tauba Auerbach: I don't like sailing either.

Bevil Conway: I'm just kidding.

Caroline Jones: We will exit and mingle out there and we will empty this room for restaging for the keynote, and I really appreciate your attention and your questions. They were wonderful. Thank you.

END OF TRANSCRIPT [01:07:09]