I want to start with a game. Okay? And to win this game, all you have to do is see the reality that's in front of you as
it really is, all right? So we have two panels here, of colored dots. And one of those dots is the same in the two panel
s. And you have to tell me which one.

00:31
Now, I narrowed it down to the gray one, the green one, and, say, the orange one. So by a show of hands, we'll start
with the easiest one. Show of hands: how many people think it's the gray one? Really? Okay. How many people thin
k it's the green one? And how many people think it's the orange one? Pretty even split.

00:58
Let's find out what the reality is. Here is the orange one.

01:04
(Laughter)

01:06
Here is the green one. And here is the gray one.

01:13
(Laughter)

01:16
So for all of you who saw that, you're complete realists. All right?

01:21
(Laughter)

01:22
So this is pretty amazing, isn't it? Because nearly every living system has evolved the ability to detect light in one w
ay or another. So for us, seeing color is one of the simplest things the brain does. And yet, even at this most fundame
ntal level, context is everything. What I'm going to talk about is not that context is everything, but why context is ev
erything. Because it's answering that question that tells us not only why we see what we do, but who we are as indivi
duals, and who we are as a society.

01:56
But first, we have to ask another question, which is, "What is color for?" And instead of telling you, I'll just show yo
u. What you see here is a jungle scene, and you see the surfaces according to the amount of light that those surfaces r
eflect. Now, can any of you see the predator that's about to jump out at you? And if you haven't seen it yet, you're de
ad, right?

02:16
(Laughter)

02:17
Can anyone see it? Anyone? No? Now let's see the surfaces according to the quality of light that they reflect. And no w you see it.

02:26
So, color enables us to see the similarities and differences between surfaces, according to the full spectrum of light t hat they reflect. But what you've just done is in many respects mathematically impossible. Why? Because, as Berkel ey tells us, we have no direct access to our physical world, other than through our senses. And the light that falls ont o our eyes is determined by multiple things in the world, not only the color of objects, but also the color of their illu mination, and the color of the space between us and those objects. You vary any one of those parameters, and you'll change the color of the light that falls onto your eye.

03:04
This is a huge problem, because it means that the same image could have an infinite number of possible real-world s ources. Let me show you what I mean. Imagine that this is the back of your eye, okay? And these are two projection s from the world. They're identical in every single way. Identical in shape, size, spectral content. They are the same, as far as your eye is concerned. And yet they come from completely different sources. The one on the right comes fr om a yellow surface, in shadow, oriented facing the left, viewed through a pinkish medium. The one on the left com es from an orange surface, under direct light, facing to the right, viewed through sort of a bluish medium. Completel y different meanings, giving rise to the exact same retinal information. And yet it's only the retinal information that we get.

04:01
So how on Earth do we even see? So if you remember anything in this next 18 minutes, remember this: that the light that falls onto your eye, sensory information, is meaningless, because it could mean literally anything. And what's tr ue for sensory information is true for information generally. There's no inherent meaning in information. It's what w e do with that information that matters.

04:25
So, how do we see? Well, we see by learning to see. The brain evolved the mechanisms for finding patterns, finding relationships in information, and associating those relationships with a behavioral meaning, a significance, by intera cting with the world. We're very aware of this in the form of more cognitive attributes, like language. I'm going to gi ve you some letter strings, and I want you to read them out for me, if you can.

04:50
Audience: "Can you read this?" "You are not reading this." "What are you reading?"

04:57
Beau Lotto: "What are you reading?" Half the letters are missing, right? There's no a priori reason why an "H" has to go between that "W" and "A." But you put one there. Why? Because in the statistics of your past experience, it wou ld have been useful to do so. So you do so again. And yet you don't put a letter after that first "T." Why? Because it wouldn't have been useful in the past. So you don't do it again.

05:19
So, let me show you how quickly our brains can redefine normality, even at the simplest thing the brain does, which is color. So if I could have the lights down up here. I want you to first notice that those two desert scenes are physica lly the same. One is simply the flipping of the other. Now I want you to look at that dot between the green and the re

d. And I want you to stare at that dot. Don't look anywhere else. We're going to look at it for about 30 seconds, whic h is a bit of a killer in an 18-minute talk.

05:49
(Laughter)

05:50
But I really want you to learn. And I'll tell you -- don't look anywhere else -- I'll tell you what's happening in your he ad. Your brain is learning, and it's learning that the right side of its visual field is under red illumination; the left side of its visual field is under green illumination. That's what it's learning. Okay? Now, when I tell you, I want you to lo ok at the dot between the two desert scenes. So why don't you do that now?

06:14
(Laughter)

06:17
Can I have the lights up again?

06:19
I take it from your response they don't look the same anymore, right?

06:23
(Applause)

06:24
Why? Because your brain is seeing that same information as if the right one is still under red light, and the left one is still under green light. That's your new normal. Okay? So, what does this mean for context? It means I can take two identical squares, put them in light and dark surrounds, and the one on the dark surround looks lighter than on the lig ht surround. What's significant is not simply the light and dark surrounds that matter. It's what those light and dark s urrounds meant for your behavior in the past.

06:50
So I'll show you what I mean. Here we have that exact same illusion. We have two identical tiles on the left, one in a dark surround, one in a light surround. And the same thing over on the right. Now, I'll reveal those two scenes, but I 'm not going to change anything within those boxes, except their meaning. And see what happens to your perception .

07:09
Notice that on the left the two tiles look nearly completely opposite: one very white and one very dark, right? Where as on the right, the two tiles look nearly the same. And yet there is still one on a dark surround, and one on a light su rround. Why? Because if the tile in that shadow were in fact in shadow, and reflecting the same amount of light to y our eye as the one outside the shadow, it would have to be more reflective -- just the laws of physics. So you see it t hat way.

07:38
Whereas on the right, the information is consistent with those two tiles being under the same light. If they're under th e same light reflecting the same amount of light to your eye, then they must be equally reflective. So you see it that way. Which means we can bring all this information together to create some incredibly strong illusions.

07:55
This is one I made a few years ago. And you'll notice you see a dark brown tile at the top, and a bright orange tile at the side. That is your perceptual reality. The physical reality is that those two tiles are the same.

08:10
Here you see four gray tiles on your left, seven gray tiles on the right. I'm not going to change those tiles at all, but I' m going to reveal the rest of the scene. And see what happens to your perception. The four blue tiles on the left are g ray. The seven yellow tiles on the right are also gray. They are the same. Okay? Don't believe me? Let's watch it aga in.

08:35
What's true for color is also true for complex perceptions of motion. So, here we have -- let's turn this around -- a dia mond. And what I'm going to do is, I'm going to hold it here, and I'm going to spin it. And for all of you, you'll see it probably spinning this direction. Now I want you to keep looking at it. Move your eyes around, blink, maybe close one eye. And suddenly it will flip, and start spinning the opposite direction. Yes? Raise your hand if you got that. Ye s? Keep blinking. Every time you blink, it will switch. So I can ask you, which direction is it rotating? How do you know? Your brain doesn't know, because both are equally likely. So depending on where it looks, it flips between th e two possibilities.

09:26
Are we the only ones that see illusions? The answer to this question is no. Even the beautiful bumblebee, with its me re one million brain cells, which is 250 times fewer cells than you have in one retina, sees illusions, does the most co mplicated things that even our most sophisticated computers can't do. So in my lab we work on bumblebees, because we can completely control their experience, and see how it alters the architecture of their brain. We do this in what we call the Bee Matrix.

09:52
Here you have the hive. You can see the queen bee, the large bee in the middle. Those are her daughters, the eggs. T hey go back and forth between this hive and the arena, via this tube. You'll see one of the bees come out here. You s ee how she has a little number on her? There's another one coming out, she also has a number on her. Now, they're n ot born that way, right? We pull them out, put them in the fridge, and they fall asleep. Then you can superglue little numbers on them.

10:21
(Laughter)

10:22
And now, in this experiment they get a reward if they go to the blue flowers. They land on the flower, stick their ton gue in there, called a proboscis, and drink sugar water. She's drinking a glass of water that's about that big to you an d I, will do that about three times, then fly. And sometimes they learn not to go to the blue, but to go where the other bees go. So they copy each other. They can count to five. They can recognize faces. And here she comes down the l adder. And she'll come into the hive, find an empty honey pot, and throw up, and that's honey.

10:54
(Laughter)

10:55
Now remember, she's supposed to be going to the blue flowers, but what are these bees doing in the upper right corner? It looks like they're going to green flowers. Now, are they getting it wrong? And the answer to the question is no. Those are actually blue flowers. But those are blue flowers under green light. So they're using the relationships between the colors to solve the puzzle, which is exactly what we do.

11:21
So, illusions are often used, especially in art, in the words of a more contemporary artist, "to demonstrate the fragility of our senses." Okay, this is complete rubbish. The senses aren't fragile. And if they were, we wouldn't be here. Instead, color tells us something completely different, that the brain didn't actually evolve to see the world the way it is. We can't. Instead, the brain evolved to see the world the way it was useful to see in the past. And how we see is by continually redefining normality.

11:56
So, how can we take this incredible capacity of plasticity of the brain and get people to experience their world differently? Well, one of the ways we do it in my lab and studio is we translate the light into sound, and we enable people to hear their visual world. And they can navigate the world using their ears.

12:18
Here's David on the right, and he's holding a camera. On the left is what his camera sees. And you'll see there's a faint line going across that image. That line is broken up into 32 squares. In each square, we calculate the average color. And then we just simply translate that into sound. And now he's going to turn around, close his eyes, and find a plate on the ground with his eyes closed.

12:43
(Continuous sound)

12:46
(Sound changes momentarily)

12:48
(Sound changes momentarily)

12:51
(Sound changes momentarily)

12:55
(Sound changes momentarily)

12:59
(Sound changes momentarily)

13:02
Beau Lotto: He finds it. Amazing, right? So not only can we create a prosthetic for the visually impaired, but we can also investigate how people literally make sense of the world. But we can also do something else. We can also make music with color. So, working with kids, they created images, thinking about what might the images you see sound like if we could listen to them. And then we translated these images. And this is one of those images. And this is a six-year-old child composing a piece of music for a 32-piece orchestra. And this is what it sounds like.

13:36
(Electronic representation of orchestral music)

14:03
So, a six-year-old child. Okay?

14:05
Now, what does all this mean? What this suggests is that no one is an outside observer of nature, okay? We're not defined by our central properties, by the bits that make us up. We're defined by our environment and our interaction with that environment, by our ecology. And that ecology is necessarily relative, historical and empirical. So, what I'd like to finish with is this over here. Because what I've been trying to do is really celebrate uncertainty. Because I think only through uncertainty is there potential for understanding.

14:41
So, if some of you are still feeling a bit too certain, I'd like to do this one. So, if we have the lights down. And what we have here -- Can everyone see 25 purple surfaces on your left, and 25, call it yellowish, surfaces on your right? So now, what I want to do, I'm going to put the middle nine surfaces here under yellow illumination, by simply putting a filter behind them. Now you can see that changes the light that's coming through there, right? Because now the light is going through a yellowish filter and then a purplish filter. I'm going to do the opposite on the left here. I'm going to put the middle nine under a purplish light.

15:34
Now, some of you will have noticed that the consequence is that the light coming through those middle nine on the right, or your left, is exactly the same as the light coming through the middle nine on your right. Agreed? Yes? Okay. So they are physically the same. Let's pull the covers off. Now remember -- you know that the middle nine are exactly the same. Do they look the same? No. The question is, "Is that an illusion?" And I'll leave you with that.

16:13
So, thank you very much.

16:14
(Laughter)

16:15
(Applause)