SPACE INVADERS

What is the holy grail of colour measurement? Rick Auterson examines three-dimensional colour space models that help users to avoid expensive mistakes

Choosing a method for expressing colour difference is a crucial decision for printing companies serving retail brands. It impacts their bottom line. To talk about colour, you only need a few words from the colour vocabulary. But to make sound business decisions, you need a profound understanding of every word you say.

Let's start by discarding equations. You do not need to understand the maths. I won't even show it to you. That sort of thing is useful to a handful of people who use far better references. All you need to know is that those equations describe shapes in three dimensions. I figured that if I could make those shapes visible, people could learn from just looking at them.

'The difference between two colours is called delta E'

I used Virtual Reality Modelling Language to map colours in three dimensions, and ringed them in wire frames to represent various colour difference methods.

The first time I looked around in one of these colour space models, I was surprised. I should not have been. I've been working with these equations for years. I thought I already knew everything. Well… I learned some fundamental truths about colour. I showed them to Mike Ruff, of Mike Ruff Consulting, and he was surprised. He should not have been. Mike actually does know everything. He said, "Imagine that."

The three-dimensional models presented here are available online. Take a deep dive and look around. You will emerge with a better understanding of colour than the experts. Besides, it's kind of fun.

HERE'S WHAT HAPPENED

In the late 1800s, the industrial revolution kicked into high gear and caught us unprepared. It demanded colour. Surprise! We had no way of measuring colour – darn it.

As it turns out, measuring colour is not that hard. Just scatter the light into its component wavelengths and measure each one. We could even compare one colour to another – and report the difference at each of three hundred wavelengths. Well… that's awkward. We needed a colour space.

The hunt began in earnest for the holy grail of colour measurement, a colour space, where, when two colours are plotted in three dimensions, their relative difference in appearance is equal to their relative distance apart. Sounds simple? We still have not figured out how to do that.

The difference between two colours is called delta E, often shortened to dE or ΔE. The little d and Δ both mean, difference. I'll stick to dE, just because there's a d on my keyboard. The purpose of delta E is to help us define an acceptable amount of colour change.

Over the years, the calculation of dE has steadily become better. But it left in its wake a series of incremental improvements. Knowing the difference between a few flavours of delta E will help you avoid potentially expensive mistakes involving colour.

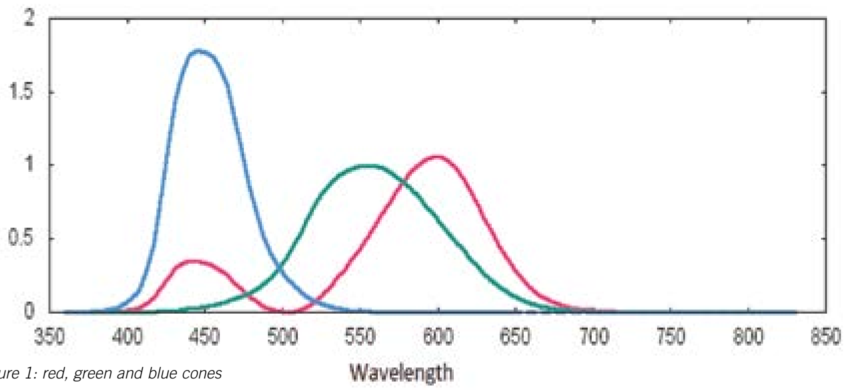


Figure 1: red, green and blue cones

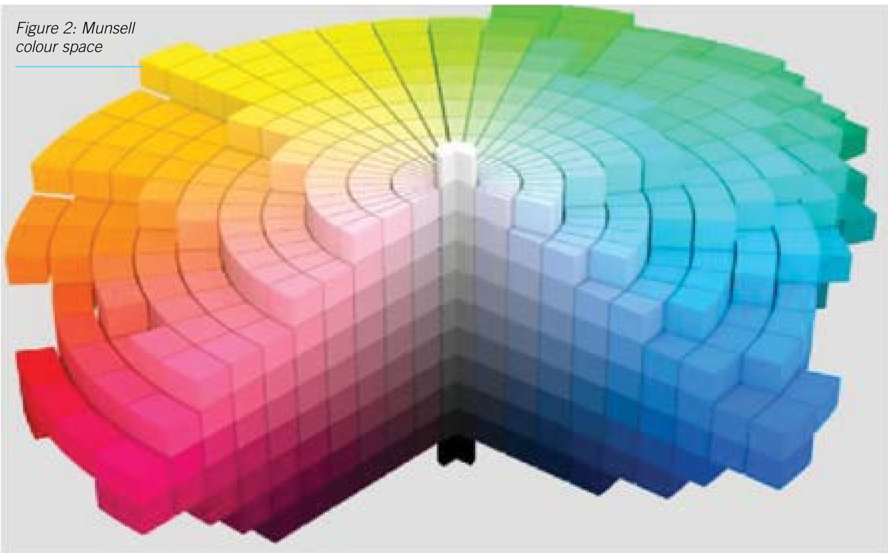


Figure 2: Munsell colour space

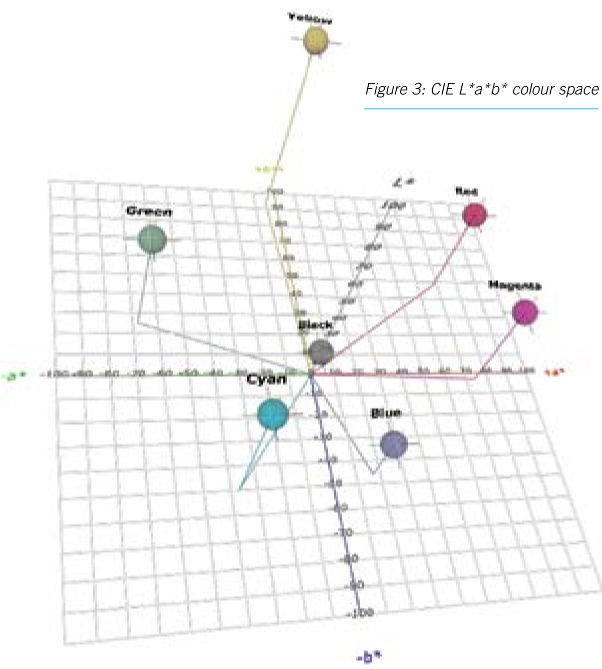


*Figure 3: CIE L*a*b* colour space*

Figure 4: CIE L*c*h colour space

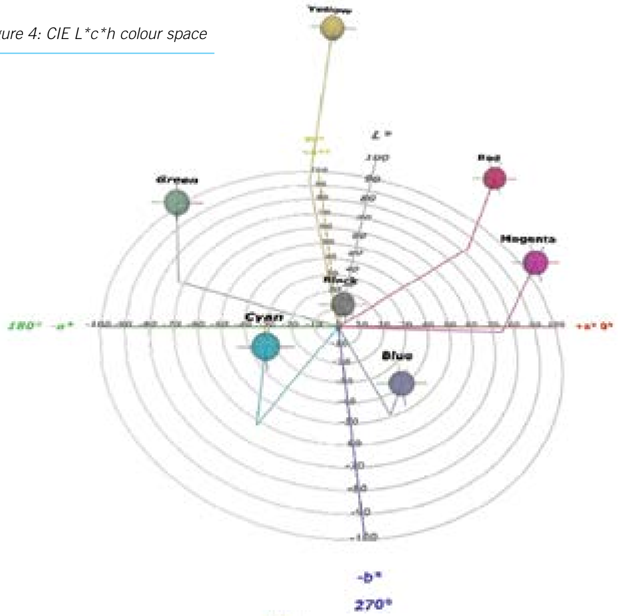
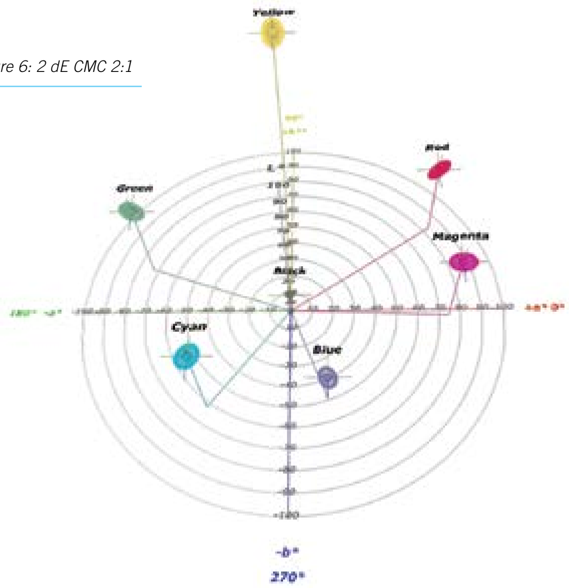


Figure 6: 2 dE CMC 2:1



Since the middle of the 1800s, people have known that the human eye has red, green and blue cones. By 1910, RGB had prompted some genius to make CMY inks. So, for decades, people tried to create a colour space with red, green and blue axes. No matter how they worked it, an RGB colour space does not agree with what people see.

Notice, illustrated in **Figure 1**, that the red cones in our eyes have

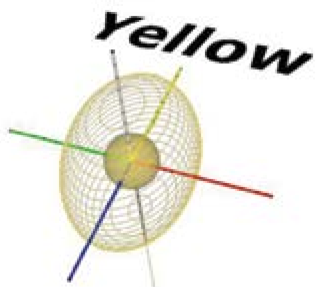


Figure 7: yellow at 2 dE CMC 2:1

Figure 8: greys and yellows in dE CMC 2:1

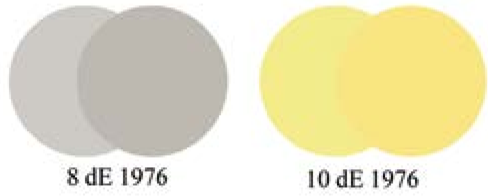


Figure 5: greys and yellows in dE 1976

problems. They react most strongly to red light, but they also react a little to blue. Blue and green cones are normal. But, again, the red cone is causing a problem. Red and green cones overlap quite a bit and share a lot of wavelengths, so we see an abundance of yellows.

Blue is the good cone, peaking a respectable distance away from the others and reacting strongly to a narrow band of wavelengths. Blues would be perfectly predictable – if the red cones were not whispering that blues are red.

Our red cones are weird; they react to nearly every visible wavelength, at least a little. Among mammals, only primates have them – presumably because red is the colour of sugars, so they can see ripe fruit. Hunters can wear those blaze orange vests because a rabbit or a deer cannot tell orange from green. Birds have red cones, but theirs

Wearing an orange vest to a duck hunt is a fashion faux pas

are normal, not like ours. Birds see reds better than we do. Wearing an orange vest to a duck hunt is a fashion faux pas. Anyway, people have these odd red cones, and they do have advantages, but they mess up what could have been a perfectly orderly and predictable colour space.

MUNSELL'S MODEL

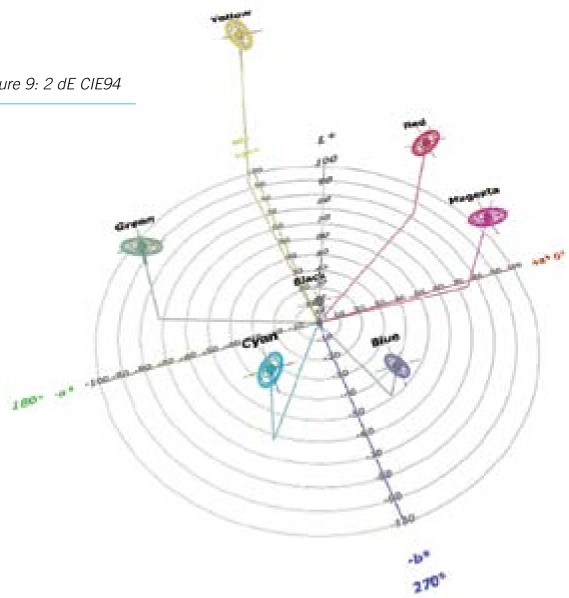
In the first decade of the 20th century, Albert Munsell, an art teacher, worked the problem backwards. He created a three-dimensional colour space by arranging coloured blocks at just-detectable changes in colour. He did this by asking people what they saw and arranged the colours accordingly.

When Munsell completed his model, people were surprised. Just look at it, right there in **Figure 2**. There's a chunk taken out to show lightness and chroma, but that is what people see and yellows occupy a quarter of the colour wheel. Imagine that.

Munsell created a colour space based upon what people see. It has four axes: red, green, blue and new to the club, yellow. The abundance of yellows caused by red cones and green ones sharing so many wavelengths was accounted for. Munsell's model went into use in the 1910s and is still in use today.

Continued over

Figure 9: 2 dE CIE94



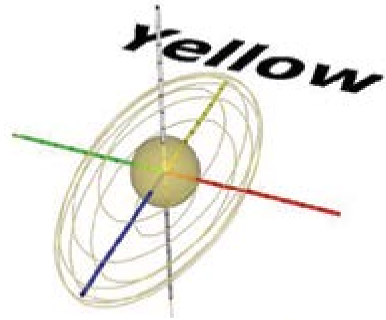


Figure 10: Yellow at 2 dE 1994

Figure 11: greys and yellows in dE 1994

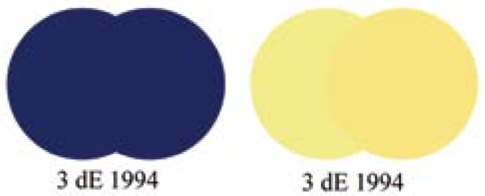


Figure 12: blues and yellows in dE 1994

CIE L*A*B* COLOUR SPACE

In 1976, the Commission Internationale de l'Eclairage (CIE), released the CIE L*a*b* colour space. Only slight revisions were made to Munsell's model. To understand what CIE L*a*b* colour space looks like, we need some colours. We'll use the CRPC-6 sheetfed offset colours—for no other reason than it gives us a wide range of colours to look over and printers are familiar with them.

As shown in **Figure 3,** CIE L*a*b* colour space is three-dimensional. The L* dimension, representing lightness, is up and down. When a* is positive, the colour is red. When a* is negative, the colour is green. When b* is positive, the colour is yellow. When b* is negative, the colour is blue. The CIE L*a*b* colour space was shaped by what people see, so red-green and yellow-blue are opposing colours. There is no such thing as a reddish green or a bluish yellow.

The distance between any two colours in this new colour space was called delta E. In **Figure 3**, using the 1976 colour difference method, a sphere with a radius of 5 maps out the points that are 5 dE from the target.

In **Figure 4**, the colour space is labelled in terms of chroma and hue. Hue is an angle, with the red axis at 0°. Chroma is the distance from the centre. I just added the angles and drew circles on the floor instead of a grid. CIE L*a*b* and CIE L*C*h are the same thing. If you were giving directions to red, you could say, go 68 on the red axis, then go 48 on yellow. Or, you could say, take a heading of 35° and go 83. Both ways take you to the same place – the same colour. Either way, once you get there you have to go 47 straight up, to represent the lightness of that red. Should the need arise, there are online calculators that convert L*a*b* and L*C*h back and forth.

'Those greys look more than twice as far apart as the yellows'

Well… the 1976 colour difference method doesn't work. In **Figure 5**, both pairs of colours are about the same distance apart in colour space, so their relative difference in appearance should be about the same. I'm close to passing those yellows, but the greys are off.

COLOUR MEASUREMENT COMMITTEE

In 1984, the Society of Dyers and Colourists, released a standard for colour difference based upon hue and chroma. They had come to terms with the colour space problem. They gave up. They stopped trying to make the perfect colour space and tweaked the calculation for delta E instead. From this point on, the distance apart in colour space would no longer be delta E. And when someone said delta E, they had to specify which method was used to calculate it.

They named it after themselves, the Colour Measurement Committee, so CMC l:c. The little l and c, are weights given to lightness and chroma. In general, CMC 2:1 is considered acceptable and CMC 1:1 is considered perceptible. It's a bit of a problem, making it adjustable like that. Honestly, I don't get the whole perceptible and acceptable thing. You still have to agree upon a delta E.

As shown in **Figure 6**, CMC creates ellipses around the targets, pointing to the centre. The ellipses are longer than they are wide, so

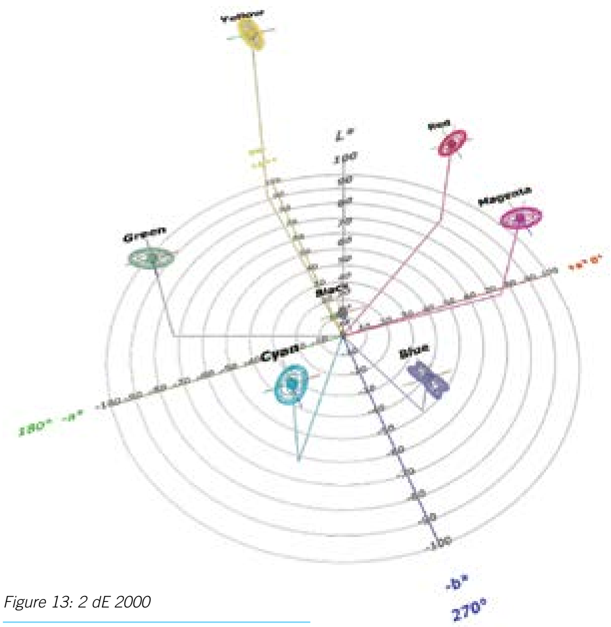


Figure 13: 2 dE 2000

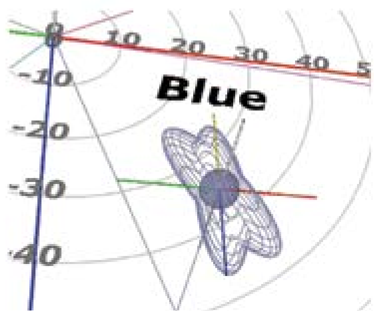


Figure 14: blue at 2 dE 2000

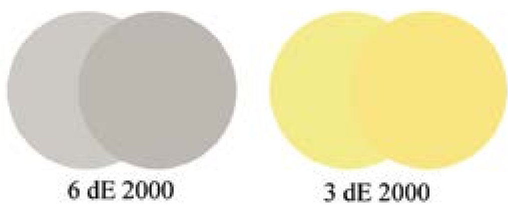


Figure 15: greys and yellows in dE 2000

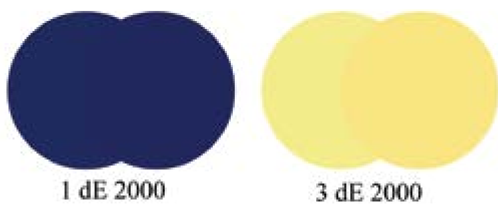


Figure 16: blues and yellows in dE 2000

CMC allows less change in hue than chroma. The size of the ellipse depends upon the colour. The spheres have a radius of 2. The wire frames around them map out the points, at which, the colour is 2 dE CMC 2:1 from the target. Look how narrow red is. That says we pick up changes in the hues of reds better than anything. Is that true?

Let's zoom in on yellow. In **Figure 7**, while dE CMC does not have an actual size of 2, it does have a size and is shaped like an M&M. The sphere at the centre has a radius of 2, so for this yellow, dE CMC 2:1 is larger than dE 1976.

Does it work? According to dE CMC 2:1, the greys in **Figure 8** are a better match than the yellows. Well… good try fellas. At least you are not still telling me those yellows are 10 apart.

CIE DE94

In 1995, the Commission Internationale de l'Eclairage, released the CIE dE94 colour difference method. I usually put a 19 in front, so dE 1994, just for consistency's sake – a slight Y2K issue.

In **Figure 9**, you can see that the ellipses got longer, so dE 1994 allows more change in chroma than CMC. Note that the red ellipse got fatter, allowing more change in the hue of reds. I'm in agreement with that.

Let's go down there and have a closer look at yellow. In **Figure 10**, we see that dE 1994 is flattened compared to CMC, so it allows less change in lightness. The shape is exactly as thick as the sphere within it. Every colour but black is shaped like a flattened football, all the same thickness and all pointing to the centre. dE 1994 does not correct for lightness. It assumes the 1976 colour space got changes in lightness right. In **Figure 11**, those greys look like they're more than twice as far apart as the yellows.

Well… it did not take long for people to realise the lightness thing isn't right. And it has trouble with blues.

In **Figure 12**, both colours are redder by the same amount. I can't tell those blues apart, but I can clearly see a difference in the yellows. When we look at a deep blue, our blue cones shout out, "BLUE!" And our red cones say quietly, "That's red."

CIE DE2000

In 2000, the Commission internationale de l'éclairage, released the CIE dE2000 colour difference method. In **Figure 13**, the first thing that jumps out is blue. What's going on with blue? Let's go down there and have a look.

In **Figure 14**, blue is two footballs joined together. The red cone's odd habit of reacting to blue light has its own ellipse – pointing at red. All the saturated colour is still footballs, but they have varying amounts of air in them. Yellow is fully inflated.

The delta E values in **Figure 15** look pretty good, but what about the blue problem?

From the looks of **Figure 16**, dE 2000 correctly predicts differences in appearance.

Good job CIE! Party at Mike's place.

CONCLUSION

There are three things you should take from all this:

- CIE L*a*b* is not a perfect colour space, but we are still using it.
- CIE L*a*b* and CIE L*C*h are the same thing.
- The dE 2000 colour difference method agrees with what we see.

All the rest is just a story about colour. ■

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