### **Dimensions of Colour for Artists**

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In addition to being presented at the Munsell Centennial Symposium as a three-hour tutorial and as a poster, this paper was also presented as a live webinar *The New Anatomy of Colour* for the ISCC as their event to celebrate AIC International Colour Day 2018. A recording of the webinar can be accessed without charge via the ISCC website or at: *https://register.gotowebinar.com/register/7440182269094639874* 

The system of *hue*, *lightness* and *chroma* is the predominant colour model familiar to painters, but other attributes of perceived colour including *brightness*, *colourfulness*, *saturation* and *brilliance* are also useful for framing and solving colour problems. Art and design educators should use these terms in line with current standard definitions, though some of the latter need to be paraphrased and illustrated to be intelligible to students. Scientific explanations of these attributes must be simple enough to be intelligible, but should not undermine understanding of colour by implying that attributes like hue are physical properties of objects and light. Rather, they should reflect the scientific consensus that perceived-colour attributes are *ways of seeing* certain physical properties of objects and light.

The **hue** of an object or a light is the colour perceived to be most similar in the cycle redyellow-green-blue-red and their intermediates. *Hue is the way in which we perceive a direction of bias among the long-, middle and short-wavelength components of the spectral reflectance of an object, or of the spectral power distribution of a light relative to daylight.* 

Formal hue scales used by painters include the Munsell hue scale and hue angle in CIELAB and CIECAM02, though for many purposes a generic hue scale structured around the four unique hues would suffice. Based on the hues conventionally assigned to artists' pigments, middle red, yellow, green and blue in artists' usage correspond approximately to Munsell 5R, 5Y, 7.5G and 5PB respectively. Even simpler hue scales structured around the three historical "primary colours" red, yellow and blue are still very widely used, but are problematic in several ways, for example in being very uneven perceptually and in encouraging the obsolete notion that the colour green is "made of" yellow and blue. For paint mixing (only), palette-based circles structured around specific paints and their paint-mixing complementaries are a useful mnemonic. Digital painters mostly use hue angle (H) of HSB space, a perceptually uneven scale structured around the RGB additive primaries.

The **lightness** of an object may be defined as its least contrasting match on a scale from black to white. Lightness (usually called *tone* or *value* by painters) is *the way in which we perceive an object's efficiency as a diffuse reflector of light*, that is, its *diffuse luminous reflectance*. Lightness is so important representationally and compositionally that it is often treated in art education as a visual element distinct from and of greater importance than "colour", meaning hue and chroma. Many painters think of lightness only in relative terms, but employment of an absolute scale is more common and more clearly beneficial for lightness than for any other colour attribute. Munsell value and (in digital painting) CIE L\* are the most widely used absolute scales.

**Chroma** is the strength of perceived colour of an object, that is, how much that colour differs from the least contrasting grey. *Chroma is the way in which we perceive an object's efficiency as a spectrally selective reflector/transmitter of light*. For a digital colour chroma correlates with the *absolute* imbalance among its nonlinear RGB components. The chroma scales of the *Munsell Book of Color* are the most commonly used formal scales, but most painters think of chroma only in relative terms.

Hue, lightness and chroma suffice to describe colours of objects including paints, but the appearance of a real or imagined scene involves not only colours seen as belonging to objects, but also colours pertaining to the light at each point in the visual field. These colours can be compared in terms of *hue, brightness and colourfulness*. **Brightness** *is the way in which we perceive visible energy of light or luminance* (from either a light-emitting or light-reflecting area), while **colourfulness** is *the way in which we perceive the absolute amount of bias between the long-, middle and short-wavelength components of a light relative to daylight*. Representational painters translate the brightness and colourfulness of each part of the visual field into lightness and colourfulness in their subjects in terms of the lightness and colourfulness of the paints short will use to represent them.

Judgments of relative brightness are surprisingly easily confounded with perceptions of object-colour lightness, presumably because of the paramount usefulness (when not painting!) of object-colour perception. Colour constancy illusions like Adelson's checker shadow figure demonstrate this clearly. Painters know from experience that their casual impressions of relative brightness can be very different from the results of careful comparison, for example with a Munsell chip or value scale held at a fixed angle, or by the technique of "squinting" or looking at the subject through nearly closed eyes.

**Saturation**, or colourfulness relative to brightness, or "freedom from white light", is *the way in which we perceive the relative amount of bias between the long-, middle- and short-wavelength components of a light, compared to daylight*. (Note however that the word "saturation" is still widely used by artists in a scientifically obsolete sense to mean chroma as defined by the CIE). For a digital colour saturation correlates with the proportional imbalance among its RGB components. Saturation is a very useful concept for representational painters in that an area of an image displaying uniform hue and saturation and varying brightness tends to read as a uniformly coloured object under varying levels of illumination.

**Brilliance** is not among the attributes of perceived colour currently defined by the CIE, but it or and its converse *blackness* have been discussed by such authors as Hering, Ostwald, Pope and Evans. Brilliance can be defined as relative brightness on a scale of appearance from black through decreasing perceived black content to a point of zero blackness (Evans' "zero greyness" or  $G_0$ ) followed by fluorence (perceived fluorescence) and then luminosity. Brilliance seems to be *the way in which we perceive the brightness of an area relative to an "expected" maximum for a non-luminous object of its hue and saturation.* 

Lines of uniform brilliance/blackness descend outwards on a Munsell hue page, more steeply for some hues than others, such that a series of colours of uniform value decreases in blackness and increases in brilliance as it increases in chroma. This increase in brilliance can create the *impression* of increased brightness and lightness (the Helmholtz-Kolrausch effect), but the luminance-based lightness measured by Munsell value or CIE L\* can nevertheless be determined by finding the least contrasting juxtaposed grey (assisted by "squinting").

### Seven attributes of perceived colour

- Hue (CIE 2011 17-542)
- Brightness (CIE, 2011, 17-111)
- Lightness (CIE 2011, 17-680) (= [greyscale] value, tone)
- Colourfulness (CIE, 2011, 17-233)
- Saturation (CIE, 2011, 17-1136)
- Chroma (CIE 2011, 17-139)
- Brilliance (inverse of *blackness* of NCS and other systems)

CIE (Commission Internationale de l'Eclairage Internationale Beleuchtungskommission

CIE (Commission Internationale de L'Eclairage/ International Commission on Illumination), 2011. *International Lighting Vocabulary*. CIE S 017/E:2011. Searchable online at <a href="http://eilv.cie.co.at/">http://eilv.cie.co.at/</a>





Sir Isaac Newton held that colours are mental "Sensations" and that what we commonly call the colour of a light is its disposition to evoke a particular colour sensation. He further demonstrated that this disposition depends on the mutual balance ("center of gravity") of what we now call the *spectral power distribution* of the light considered as a two-dimensional system.

"For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour." ----Newton, Opticks, 1704

### Colours of objects



Newton also established that colour "in the Object" is the object's disposition to reflect some "Rays" more strongly than others (now its *spectral reflectance)*, which he revealed by shining a solar spectrum onto various artists' pigments.

"...Colours in the Object are nothing but a Disposition to reflect this or that sort of Rays more copiously than the rest;..."

#### --- Isaac Newton, Opticks, 1704

In the view of colour founded by Newton and implicit in current CIE terminology, attributes of perceived colour such as hue should be understood not as physical properties of lights and objects "detected" by the eye but as the **ways we perceive** various aspects of their physical properties.



#### Hue

The **hue** of a light or of an object is the most similar colour in the cycle red-yellow-green-blue-red and their intermediates.

**Hue**: "attribute of a visual perception according to which an area appears to be similar to one of the colours: red, yellow, green, and blue, or to a combination of adjacent pairs of these colours considered in a closed ring" (CIE, 2011, 17-542).

**Unique hue**: "hue that cannot be further described by the use of hue names other than its own. Equivalent term: "unitary hue". NOTE There are 4 unique hues: red, green, yellow and blue forming 2 pairs of opponent hues: red and green, yellow and blue." (CIE, 2011, 17-1373).



# Hues of light

The hue of a digital colour or of an isolated light is the way in which we perceive a *direction of bias among its long-, middle- and shortwavelength components.* 

If there is no long- or middle- or shortwavelength bias we perceive the screen area and the light emitted from it as **lacking** hue.

Colours having hue are called *chromatic*; colours lacking hue are called *achromatic*.



# Hues of objects

The hue we see as belonging to an object is the way in which we perceive a direction of bias among the long-, middleand short-wavelength components of its *spectral reflectance*.

If there is no long-/ middle-/ short-wavelength bias in the spectral reflectance we perceive the object as **lacking** hue (being neutral or achromatic).



### Lightness

The lightness of any object colour is the least contrasting step on a scale from black to white, such as the Munsell value scale or L\* in CIE L\*a\*b\*. Alternative names for lightness include *tone*, *value* and *greyscale value*.

**Lightness**: "brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting" (CIE 2011, 17-680).

The phrase "similarly illuminated area" in the standard CIE definition implies that when we perceive lightness in an area, that area is perceived as something that is being illuminated. Notice also the implication that in addition to having a perception of lightness relative to a white object, we also have a separate perception of brightness (see below) from the same area.

Representationally and compositionally, lightness is the most important attribute of colour for painters, and the first one that every beginning painter must master.



From Cleland (1921), Practical Description of The Munsell Color System.

# Lightness

Lightness is the way in which we perceive an object's *luminous reflectance/ transmission*, that is, its efficiency as a diffuse reflector/ transmitter of light. Munsell chips of the same value are designed to reflect light of the same *luminance* (light energy as perceived by the human eye) under a standard daylight illuminant.

If we follow a horizontal series of Munsell chips of the same value and increasing chroma, the chips increase in an attribute called *brilliance* (see below), which can give the impression of an increase in brightness. Despite this effect, the luminance-based Munsell value of a sample can be determined by placing it adjacent to a Munsell value scale and finding the *least contrasting* grey. The painter's trick of "squinting" (viewing through nearly closed eyes) helps here.

### Chroma

**Chroma** is the intrinsic strength of colour of an object, that is, the visual difference from the least contrasting neutral grey. The chroma of an object (including a paint) is the way in which we perceive the absolute amount of bias among the long-, middle- and short-wavelength components its spectral reflectance, or essentially its efficiency as a spectrally selective reflector/transmitter of light.



# Chroma

**Chroma**: "colourfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears white or highly transmitting" (CIE, 2011, 17-139).

The standard perceptual definition of chroma uses the fact that the *colourfulness* (see below) of an object changes in different levels of illumination, but so does the brightness of a white object, so we can define chroma, or the **intrinsic** colourfulness of an object if you like, as the colourfulness relative to the brightness of a white object. Once again it's implicit that the area is being seen as an illuminated thing, and that we have a perception of colourfulness from the same area simultaneously with a perception of chroma that depends on comparison with another area.

While of less pressing importance than the vital attribute of lightness, careful attention to chroma provides the refinement lacking in many beginners' paintings.



# Colours of objects and colours of light



The attributes of hue, lightness and chroma suffice to describe **colours of objects** including paints, *called object colours*.

**Object colour**: "colour perceived as belonging to an object" (CIE, 2011, 17-831).

The object colour or "local" colour of an object is the way in which we perceive certain aspects of the object's physical property of *spectral reflectance*.



Spectral reflectance of Munsell 5R 5/14 chip (Zsolt Kovacs rs2color)



Brightness and colourfulness

Without having to think about it we see this red stripe as having the same object colour, that is, the same hue, lightness and chroma, over its length, and we would not be surprised to find that the stripe matches the same Munsell chip placed *beside it* in the shadow and in the light. Nevertheless, the area of the stripe in the light appears brighter and more colourful than the area in the shadow. Brightness and colourfulness are attributes of the appearance of the *light* reaching our eyes from different areas of the stripe.

**Brightness**: "attribute of a visual perception according to which an area appears to emit, or reflect, more or less light. NOTE The use of this term is not restricted to primary light sources" (CIE, 2011, 17-111).

**Colourfulness**: "attribute of a visual perception according to which the perceived colour of an area appears to be more or less chromatic" (CIE, 2011, 17-233).

Brightness is the way in which we perceive luminance, and colourfulness is the way in which we perceive the absolute amount of bias between the long-, middle and shortwavelength components of a light relative to daylight.

# Brightness and colourfulness



The appearance of a real or imagined scene involves not only colors seen as belonging to objects, but also colors pertaining to the *light* at each point in the visual field.

#### **Object colour** Light colours

Paint colours

Higher brightness Higher colourfulness Higher chroma

**Higher lightness** 

Same lightness Same chroma

> Lower brightness Lower colourfulness

Lower lightness Lower chroma

Painters translate brightness and colourfulness of the light from a real or imagined scene into the lightness and chroma of the paints they use to depict it.



### **Brightness**

Precise comparisons of relative brightness in the visual field are surprisingly difficult to make, and can be strongly influenced by the colours seen as belonging to objects, as the Adelson checkerboard illusion shows. Areas A and B give off the same amount of light, but area B gives an impression of being brighter to many observers. However to paint this scene we would need to use the same paint on both areas. Painters experience situations like this all the time and know that their casual impressions of relative brightness can be very different from the results of careful comparison, for example with a Munsell chip or value scale held at a fixed angle. The painter's trick of squinting also helps in seeing A and B as equally bright.

# Colours of objects and colours of light



Primary light sources *perceived as light sources* can be compared in terms of brightness, that is, as being brighter or dimmer than each other, but are not seen as having a greyscale value such as middle grey.

A computer or television screen is a primary light source, but we normally perceive it as if it was a illuminated page, and so we normally do perceive colours on the screen as having lightness (greyscale value) and chroma.



Same saturation in light and shade

### Saturation

Many artists use the word saturation in a scientifically obsolete sense, to mean chroma as defined by the CIE.

Saturation as defined in CIE terminology expresses a relationship that can be very important to painters. Namely, the colourfulness and brightness of the light reflected diffusely by a uniformly coloured object tend to increase proportionately as the intensity of illumination increases, so that the colourfulness relative to the brightness, called the *saturation*, remains roughly constant.

**Saturation**: "colourfulness of an area judged in proportion to its brightness" (CIE, 2011, 17-1136).

The only way that a light can be less colourful but have the same brightness is for it to be more whitish, so saturation can also be described as freedom from whitishness of light.



Lines of uniform saturation, which equates to equal chroma relative to lightness.

### Saturation

Now, since painters depict the brightness and colourfulness of their subjects with the lightness and chroma of their paints, to maintain this relationship of uniform saturation we would expect to have to depict objects using a series of paints (*shading series*) in which the chroma relative to lightness stays the same. We can also reach the same conclusion from the definitions: lightness and chroma are brightness and colourfulness relative to the same thing, so uniform saturation should equate to uniform chroma relative to lightness.

On a Munsell hue page lines of equal chroma relative to lightness radiate from zero on Munsell value scale, in contrast to lines of equal chroma which are vertical. In practice shading series, which correspond to lines of uniform *chromaticity*, are found to radiate quite like this, through on average from a point about one value step below zero on the Munsell scale, and may drift somewhat in Munsell hue.



Lines of uniform saturation read as shading series.

The diagram on the left consists of nothing more than seven uniform saturation series (including the achromatic surround), but clearly reads as a series of uniformly coloured stripes under varying illumination. Our visual system evidently uses relationships of uniform saturation, or at least the stimulus relationships we perceive as uniform saturation, in parsing the visual field into object colours and illumination.

### Saturation and brilliance



The framework of saturation and brilliance, like that of lightness and chroma, was crystallized by an artist and art teacher. Arthur Pope (1880-1974) recognized that the scientists of his time were using the word "saturation" in two different senses, corresponding to saturation and chroma in current CIE terminology. The concept of brilliance was greatly elaborated by Kodak research scientist Ralph Evans, who warmly acknowledged Pope's contribution in the final chapter of his 1974 book *The Perception of Color*.



### Saturation and brilliance



The framework of saturation and brilliance is an aid to understanding and evoking effects of **luminosity** and **illumination**. Arthur Pope explained that under different levels of the same illuminant, a uniformly coloured object will be depicted using a series of image colours having the same hue and saturation and varying brilliance, and that for a multi-coloured object these image colours maintain the same *relative* brilliance at each level of illumination. The digital colour space HSB (or HSV) allows us to easily apply Pope's principles to finding colour relationships that evoke effects of illumination, as these digital realizations (right) of some of Pope's diagrams from 1922 show.

### Chroma, colourfulness and saturation



Digital colours can be considered both as object colours having chroma and as lights having colourfulness and saturation.

The chroma of a screen colour is the way in which we perceive the *absolute* amount of bias among its long-, middleand short-wavelength components (in nonlinear RGB units).

Similarly the colourfulness of a light is the way in which we perceive the *absolute* amount of bias among its long-, middle- and short-wavelength components, relative to daylight.

Saturation is the way in which we perceive the *relative* or *proportional* imbalance among the long-, middleand short-wavelength components of a light (in nonlinear RGB units).



Lines of decreasing blackness and increasing brilliance

### Brilliance

Consider a series of colours along a line of uniform saturation. Beginning with black, we pass through colours that appear to have a large black content, and as we proceed this black content decreases to a point *of zero blackness*. The brightness at which this point of zero blackness occurs varies greatly for different hues and saturations. If we continued to increase the brightness while maintaining the hue and saturation we would pass into colours exhibiting *fluorence* (perceived fluorescence) and then *luminosity*.

**Brilliance** (inverse = **blackness**) could thus be defined as a scale of decreasing black content, from black to zero blackness, followed by fluorence and then luminosity.

Brilliance is the way in which we perceive the brightness of an area relative to an expected maximum for a non-luminous object of its hue and saturation.

### Brilliance



The tile in the middle of the top face passes from (1) black to (2) high blackness, (3) low blackness, (4) zero blackness, (5) fluorence and (6) luminosity as it increases its brightness while keeping its hue and saturation the same. The tile reaches zero blackness at a brightness between those of the zero-blackness red and yellow squares.

These illustrations are variations on an optical illusion by Purves and Lotto (*Why We See What We Do*, 2003) in which two physically matching image areas depict tiles exhibiting blackness and fluorence respectively (next slide). In this alarming illusion it is almost impossible to see these image areas as having the same colour. Purves and Lotto thought that this and other illusions including the Adelson checkerboard illusion (above) are evidence that "what we see deviates from physical measurements of objects and conditions in the real world".



Brilliance

While this is certainly true in several ways, what these illusions specifically demonstrate is that when we look at an **image** of illuminated objects our perception is dominated by the colours we perceive to belong to the virtual objects that are depicted. Paradoxically our ability to parse the visual field into object properties (seen as their colours) and illumination is so effective and automatic that it is very difficult to compare properties of the image surface itself, unless we break the representational spell of the image in some way (below).

This is not surprising: the main value of vision to us is in representing properties of objects rather than properties of the visual field, so the colours we tend to notice are those relating to the former. We didn't need to concern ourselves with the latter at all until we began to paint appearances. Fortunately for painters, relationships within the visual field are not permanently inaccessible to us, but we are not used to looking for them, so they often hide in plain sight! Painters deal with the difficulty in judging relative luminance accurately by using devices such as squinting, comparison with a Munsell chip or a value scale held at a fixed angle, or the use of a screen with two apertures.

Original image by Purves and Lotto (2003)

### Seven attributes of colour for painters

- **Hue:** the most similar colour in the cycle red-yellow-green-blue-red and their intermediates.
- Lightness (= value, greyscale value, tone): the least contrasting step on a scale from black through neutral greys to white.
- **Chroma:** the intrinsic chromatic strength of an object colour, that is, its visual difference from the least contrasting neutral grey.
- Brightness: the perceived amount of light coming from an area.
- Colourfulness: the chromatic strength of the light coming from an area.
- **Saturation:** the chromatic purity or relative freedom from white of the light coming from an area.
- **Brilliance** (inverse = **blackness**): a scale of decreasing black content, from black to zero blackness, followed by fluorence (perceived fluorescence) and then luminosity.

*Hue, lightness* and *chroma* are the attributes of colour most familiar to painters, and are sufficient to describe the colours of objects including paints. *Hue, brightness* and *colourfulness* describe the *light* we see coming from objects and evoke by means of the hue, lightness and chroma of our paints. The framework of *hue, saturation* and *brilliance* is an aid to understanding and evoking effects of luminosity and illumination.

### Physical associations of the attributes

- **Hue** is the way in which we perceive a direction of bias among the long-, middle- and short-wavelength components of the reflectance of an object, or of the spectral power distribution of a light relative to daylight.
- **Lightness** is the way in which we perceive an object's luminous reflectance/ transmission, that is, its efficiency as a diffuse reflector/transmitter of light.
- **Chroma** is the way in which we perceive the absolute amount of bias among the long-, middle- and short-wavelength components of the spectral reflectance of an object, or essentially its efficiency as a *spectrally selective* reflector/transmitter of light.
- Brightness is the way in which we perceive luminance (visible energy of light).
- **Colourfulness** is the way in which we perceive the absolute amount of bias between the long-, middle- and short-wavelength components of a light relative to daylight.
- **Saturation** is the way in which we perceive the *relative* amount of bias between the long-, middle- and short-wavelength components of a light, relative to daylight.
- **Brilliance** is the way in which we perceive the brightness of an area relative to an expected maximum for a non-luminous object of its hue and saturation.