# A colour survey of artist's pastels

Paul Centore

*Email: paul@isletech.net*

Spectrophotometric measurements were made of 3154 artist's chalk pastels, comprising the complete lines of eight brands (Rembrandt, Unison, Sennelier, Schmincke, Girault, Blue Earth, Mount Vision, and Great American). Text files and spreadsheets of reflectance spectra, CIE coordinates, and Munsell specifications, are made publicly available; another file lists which pastels are closest to the Munsell renotation colours. The pastels' gamut was compared to the Pointer gamut of real surface colours, which was converted to Munsell space. The Pointer gamut in Munsell space is also made publicly available. About 65 pastels, mostly light yellows and blue-purples, fall outside the Pointer gamut, suggesting that it can be extended.

*Received 08 December 2015; revised 03 March 2016; accepted 18 April 2016*

*Published online: 09 May 2016*

## Introduction

Though something of a niche, pastels are a standard painting medium that date from the 18th century [1]. Since pastels contain only enough binder to hold the sticks together, they can achieve higher pigment loads, and more saturated colours, than other painting media. Artists usually mix oil or acrylic paints on a palette, to produce a wide gamut of colours from a handful of base paints. Pastels, however, cannot be mixed on a palette, so a single pastel manufacturer typically produces a few hundred pastels, with many fine colour gradations. The plethora of colours, and the presence of some very saturated colours, make pastels useful for delineating the real colour gamut. Though some copious reflectance data sets have been assembled [2], none of them has included pastels. This paper compares the pastels' colour gamut to the 1980 Pointer gamut [3].

The basic data consists of measured reflectance spectra for 3154 pastels, comprising the complete lines of eight brands: Rembrandt, Unison, Sennelier, Schmincke, Girault, Blue Earth, Mount Vision, and Great American. To express pastel colours in intuitive perceptual terms, the reflectance spectra were converted into Munsell specifications [4-5]. The spectra were also expressed in Commission Internationale de l'Éclairage (CIE) coordinates [6] ($X$, $Y$, $Z$, $x$, $y$, $L^*$, $a^*$, $b^*$, $C^*$, $h$) under C/2 viewing conditions. A sort of reverse look-up table is provided: for each specification in the Munsell renotation [4], the closest matches in the 3154 pastels are listed. All this data is presented as both text files and spreadsheets, and is available on the JAIC website, combined into one file, named DataFilesForPastelColourSurvey.zip. Painters, manufacturers, and researchers are welcome to use this data. Along the same lines, the author is willing to lend his pastel samples to others, so that repeated measurements can lead to more accurate data.

Though this paper is believed to present the first publicly available pastel spectra, mention should be made of previous efforts by Marie Meyer, who measured over 5500 pastels to produce her *Multi-Brand Color Chart*: *Pastels* [7] displaying the pastels in terms of the Munsell system. Personal communications, however, reveal that her spectral measurements have been lost.

The Pointer gamut consists of colorimetric coordinates, calculated under C/2 viewing conditions. This viewing assumption is also made by the Munsell renotation, which classifies colours by hue, value, and chroma. Since the Munsell system is a natural perceptual system, the Pointer gamut was converted to the Munsell system, and analysis was performed in Munsell space.

The analysis showed that 67 pastel colours, mostly for Munsell values above 7, were outside the Pointer gamut, suggesting that the Pointer gamut could be extended. Almost all the outside colours occurred in the blue-purple hue region, although a few very light colours occurred in the yellows. In darker values, of 3 or less, the pastels did not fill out the Pointer gamut very well. Also, for values less than 7, the green region of the Pointer gamut included many colours for which no pastels were available. A similar lack of pastels occurred for reddish purple hues when the Munsell value was 5 or less. Apart from these gaps, the set of pastel colours covered the Pointer gamut fairly thoroughly. A table is provided of all 67 pastels whose colours were outside the Pointer gamut. Other researchers are encouraged to obtain these pastels, and verify their measurements, so that the Pointer gamut can be updated with confidence.

This paper is organised as follows. First, the pastel samples and measurement protocol are described. Next, the Munsell system and Pointer gamut are discussed, and the Pointer gamut is converted to Munsell space. The pastel gamut is then analysed in Pointer/Munsell terms. Finally, data files and spreadsheets are presented, with some recommendations for use. The paper ends with a brief summary.

## Samples and measurements

### *Description of samples*

This study measured samples of the complete line of chalk pastels from eight different brands: Rembrandt, Unison, Sennelier, Schmincke, Girault, Blue Earth, Mount Vision, and Great American. *Chalk pastels* or *soft pastels* are just traditional pastels, which typically use gum tragacanth [1] as a binder. They differ from oil pastels, which use oils or waxes as binders. In addition, some manufacturers speak of hard pastels, which are chalk pastels which contain clay or other additives, to make the pastel firmer and less manipulable. The terms *hard* and *soft* are extremes on a continuum.

Though all the pastels in this study are considered soft pastels, the Rembrandt and Girault pastels are harder than the other manufacturers'.

Table 1 lists the number of pastels by brand. In all, 3154 pastels were measured. The largest set was Great American, with 546 pastels, and the smallest set was Rembrandt, with 218 pastels. Samples were made or obtained for each of the 3154 pastels. A sample is an area of pastel, between half an inch and an inch square, applied to standard pastel paper.

| Brand | Number of Pastels |
|---|---|
| Great American | 546 |
| Sennelier | 525 |
| Unison | 422 |
| Mount Vision | 407 |
| Schmincke | 400 |
| Blue Earth | 336 |
| Girault | 300 |
| Rembrandt | 218 |
| Total | 3154 |

*Table 1: Measured pastel samples.*

Figure 1 shows some samples for Rembrandt pastels. To make the pastels, the samples were applied as thickly and smoothly as possible, usually being rubbed by a finger; ideally the sample would be opaque, covering the paper completely. The papers used were standard white pastel papers, with minimal tooth. The Rembrandt samples were made by the author on Canson Mi-Teintes paper. The Unison samples were kindly provided by Unison (based in Northumberland, England). The rest of the samples were provided by Dakota Pastels (based in Seattle, USA), on Somerset Radiant White paper.


*Figure 1: Some samples of Rembrandt pastels.*

For various reasons, no fixative was used on any of the samples. First of all, many pastelists do not use any fixative, preferring to protect a pastel painting by framing it behind glass. Second, fixatives often darken pastel colours slightly, just as some varnishes darken oil paintings slightly. Third, fixatives are not at all standardised, varying greatly from manufacturer to manufacturer in material composition, and from painter to painter in thickness of application – some pastel artists even use hairspray as a cheap but effective fixative (at least for the short term). Given all this variability, it was decided to keep the analysis focused on the pastels themselves, with no fixatives.

Each pastel brand has its own naming system, usually not very informative, for individual pastels. Since pastels often contain a mixture of pigments, the traditional artist's monenclature, in which names like cadmium yellow or viridian green denote the pigment used, cannot be applied. Some manufacturers, like Girault and Sennelier, simply assign numbers, not always consecutive, to their pastels. Rembrandt divides its set into hue series, assigning each pastel one number for its series, and a second number for its position in the series. The position numbers vary from 2 to 12, with numbers above 5 indicating tints and numbers below 5 indicating shades. For example, the Rembrandt pastel 626,10 is a light green. Other manufacturers use letters as modifiers. Schmincke, for example, uses D and H to indicate dark and light versions of a colour (D and H stand for dunkel and hell, the German words for dark and light). Unison divides its pastels into series such as Yellow Green Earth. Table 2 lists the series, along with abbreviations used in this paper. The pastels in each series are then numbered, so Yellow Green Earth 7 is the seventh pastel in that series. This paper will refer to a pastel by its brand name, plus the manufacturer's identifier for that particular pastel. For example, the two pastels mentioned in this paragraph would be Rembrandt 626,10 and Unison YGE7.

| **Series** | **Abbreviation** |
|---|---|
| Additional | A |
| Blue Green | BG |
| Blue Green Earth | BGE |
| Blue Violet | BV |
| Brown Earth | BE |
| Dark | Dark |
| Green | G |
| Grey | Grey |
| John's Set | J |
| Light | Light |
| Natural Earth | NE |
| Orange | O |
| Portrait | P |
| Red | R |
| Red Earth | RE |
| Special Collection | SC |
| Turquoise | T |
| Yellow | Y |
| Yellow Green Earth | YGE |

*Table 2: Unison pastel series.*

While most pastels contain only pigment and binders, some manufacturers have introduced additives to give special effects, such as mica flakes for iridescence. Sennelier 801 through 825 are examples. These additives affect a pastel's appearance rather than its colour *per se*. Since the number of effect pastels is small, and since they have definite colours, they were included in this analysis alongside the standard pastels.

A pastel's shelf life is effectively unlimited, and decades-old pastels are still usable. Over a long enough time, a manufacturer might change a pastel's name or formulation, so that two pastels with the same name can differ. Figure 2 shows a particularly bad example, in which two pastels, both Rembrandt 331,9, produce very different colours. Another possible cause of colour variation is manufacturing inconsistency. Slight pigment discrepancies from batch to batch, or fluctuations in the relative proportions of ingredients, can cause colour irregularities. While colour consistency was not analysed, Figure 3 shows that it could be significant when it occurs. The figure reproduces two samples, each made with a pastel labeled Sennelier 303. Though close, the two samples' colours are also slightly but definitely different. The sample on the left tends toward orange when compared with the sample on the right, which tends more toward red. While the extreme difference in Figure 2 almost certainly results from a renaming or reformulation, the difference in Figure 3 could result just as plausibly from manufacturing variability. An interesting further study would be to quantify pastel manufacturing consistency.

Fortunately, the differences in Figures 2 and 3 seem the exception rather than the rule, so no attempt was made to identify or correct for them. Instead, samples were taken from any convenient source. The pastels for the Rembrandt samples in Figure 1, for example, were taken from the artist's personal collection, borrowed from friends' collections, or, if necessary, purchased. The pastel samples for all the brands were assembled over a year and a half, from late 2013 to mid 2015.

*Figure 2 (left): Two different colours for Rembrandt 331,9.*

*Figure 3 (right): Two samples, each made with Sennelier 303.*

### *Description of measurements*

Each sample was measured with an X-Rite i1Pro2 handheld spectrophotometer. The measurement protocol consisted of three separate measurements, each of which produced a reflectance spectrum at intervals of 10 nm, for wavelengths from 380 nm to 730 nm. The measurements were with replacement: the sample and the spectrophotometer were physically separated between measurements. A median reflectance spectrum was calculated by taking the median reflectance at each wavelength. This median spectrum was taken as the final measurement. The i1Pro2 offers a choice of M0, M1, and M2 measurement geometries; the M2 geometry was used for all the analysis in this paper.

A pastel sample's dusty surface makes measurement difficult. Just touching a pastel painting will likely make some powder come off. The i1Pro2, which is a contact spectrophotometer, tended to disturb the samples' surfaces, limiting the number of repetitions. In addition, the spectrophotometer needed frequent cleanings, to remove bits of pigment dust.

A related surface issue is the texture of the substrate used for the pastel samples. Both the Canson Mi-Teintes paper and the Somerset Radiant White paper, as well as the unidentified paper used for the Unison samples, have a slight tooth, which can be seen in Figure 3. Although the thick pastel layer covers the paper completely, the paper's tooth is still visible, and can presumably introduce some random fluctuations into spectrophotometric readings. To allow multiple layers of pastels, almost all pastel papers have at least some minimal surface unevenness, so, like a pastel's dustiness, paper texture seems to be an unavoidable source of error.

These surface factors made the pastel measurements rather variable. To quantify variability, the mean colour difference from the mean [8] (MCDM) was calculated for a sheet of 56 Sennelier samples. Since this paper uses the Munsell system to analyse pastel colours, C/2 viewing conditions were assumed. The MCDM calculation used the $\Delta E_{00}$ colour difference expression [6, 9], also referred to as DE or DE00. Each of the 56 samples was measured 10 times with the i1Pro2, and 56 MCDMs were calculated. The mean MCDM for the 56 pastel samples was just over 1 $\Delta E_{00}$ unit. For comparison, the mean MCDMs for glossy printed colours [10], measured with the same spectrophotometer, were near 0.2 $\Delta E_{00}$ units. Measurement variability, likely caused by the irregular pastel surfaces, is probably the weakest point in the analysis presented in this paper.

A more indirect measurement problem is clerical error. Most samples were prepared by third parties; the author himself received samples of pastels, but not the actual pastels. Since a single set contains hundreds of pastels, of finely gradated colours, it is easy to select the wrong pastel occasionally, or fill in the wrong square on the page of samples. The author came across several of these mistakes in the course of analysis, and corrected them when found. Given the large number of pastels, however, likely other clerical errors have slipped through.

## The Munsell system and the Pointer gamut

Analysing pastel colours, or colours in general, requires a systematic language. The long-established Munsell system provides such a language, using terms that are natural to artists. While the Munsell system aims to delineate all the surface colours that can occur physically, the 1980 Pointer gamut [3] aims to delineate all the surface colours, either natural or man-made, that actually do occur. Though originally expressed in CIE coordinates, the Pointer gamut can also be expressed more intuitively in Munsell coordinates. This section will describe both the Munsell system and the Pointer gamut, and then present a Munsell table of the Pointer gamut, analogous to Pointer's original CIE tables.

### *The Munsell system*

At the start of the 20th century, Albert Munsell developed a colour system that is tailored to the visual arts. The system classifies surface colours by three perceptual attributes that are basic to painting: hue, value and chroma.

Hue is universally understood. It says whether a colour is red, yellow, purple, etc. Munsell designates 10 basic hues: R (red), YR (yellow-red, or orange), Y (yellow), GY (green-yellow), G (green), BG (blue-green), B (blue), PB (purple-blue), P (purple), and RP (red-purple). Each basic hue is further subdivided into 4 steps, denoted with a prefix. For example, the four greens are denoted 2.5G, 5G, 7.5G, and 10G. 2.5G is a yellower green, that is closer to GY than it is to BG. 10G is a bluer green, that is closer to BG than it is to GY. In all, then, the Munsell system specifies 40 hues (4 steps for each of the 10 basic hues). These 40 hues are equally spaced perceptually. One could interpolate any desired amount between two adjacent hues. For example, the hue 6GY is a yellowish green that is between 5GY and 7.5GY, but perceptually more similar to 5GY. White, black, and greys are not considered hues in the Munsell system. Rather, they are designated N, for “neutral”.

Many different colours can have the same hue. Figure 4, for example, shows the “hue leaf” for 6GY, a set of colours all of which have hue 6GY. The different colours within a hue leaf are specified further by value and chroma. The empty boxes indicate colours that are in the Munsell system, but that are beyond the gamut of the printing process used to produce the figure. The hue leaf shades smoothly into the neutral axis, consisting of greys, shown on the left.

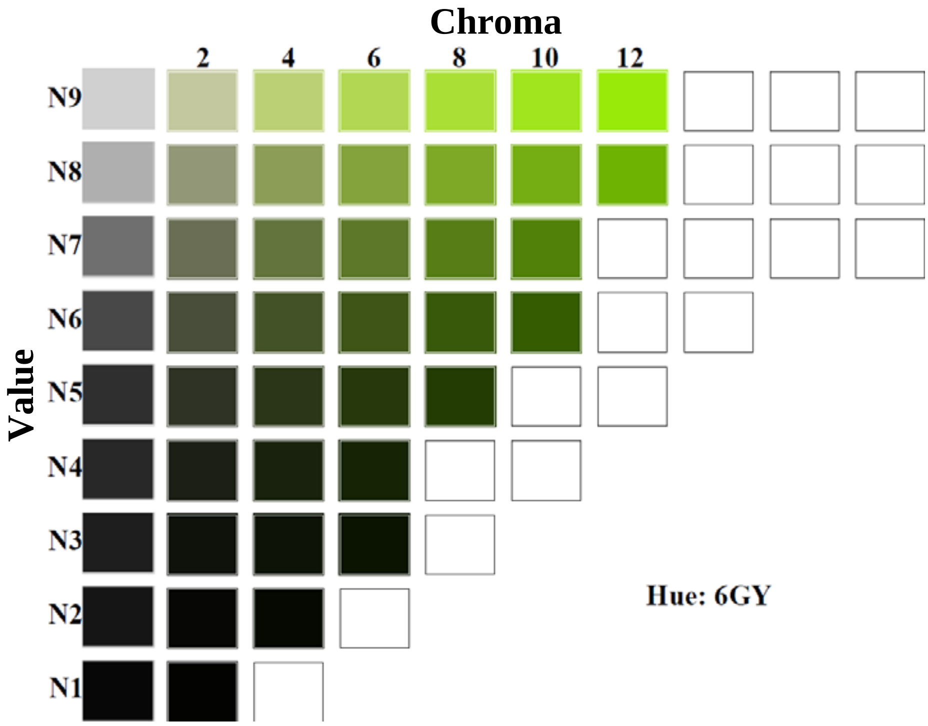


*Figure 4: The hue leaf for 6GY in the Munsell system.*

Munsell value designates how light or dark a colour is. The theoretically darkest black has a value of 0, and is denoted N0. The theoretically lightest white has a value of 10, and is denoted N10. Between N0 and N10 are 9 progressively lighter greys, denoted N1 through N9. The spacing between the greys is perceptually equal. All colours have a Munsell value, not just the neutrals. For example, there are light blues and dark blues. A blue with value 8.5 has the same lightness as N8.5.

Munsell chroma refers to how intense, or saturated, a colour is. For example, a lemon is an intense yellow, while masking tape is a dull yellow. A dull colour is closer to a neutral grey than an intense colour. The Munsell system denotes chroma numerically. Greys have chroma 0. A colour with a chroma of 10 or higher is generally perceived as saturated. Colours of low chroma, say 4 or less, are perceived as subdued, with a high grey content.

The Munsell notation for a colour takes the form H V/C, where H stands for hue, V stands for value, and C stands for chroma. For example, the colour 10R 9/6 would be a very light (V is 9), moderately intense (C is 6), orangish red (H is 10R). A colour with chroma 0 is a neutral grey, which is denoted NV, where V stands for value. For example, N5 is a grey that is midway between white and black.

Early versions of the Munsell system were collections of intuitively chosen hand-painted swatches, which served as physical standards for judging other colours. The 1943 Munsell renotation [4], which is the standard today, defined the system scientifically. The renotation used thousands of visual assessments of paint samples, by 41 human observers, to provide a firm empirical basis for the system. In addition, the renotation specified a set of 2,745 Munsell colours quantitatively, in terms of CIE coordinates. By interpolating between the 2,745 specified Munsell colours, CIE coordinates can be found for any other Munsell expressions. While the renotation calculates CIE coordinates from Munsell coordinates, it is also possible to invert [5] the renotation, so that one can calculate a Munsell specification from a set of CIE coordinates. The Munsell renotation assumes that samples are observed under Illuminant C, by the 1931 Standard Observer.

### *The Pointer gamut*

A surface colour is defined physically by its reflectance spectrum, $\rho(\lambda)$, where $\lambda$ is a wavelength in the visible spectrum, which extends from about 400 to 700 nm. The function $\rho(\lambda)$ gives the percentage of incoming light of wavelength $\lambda$ that the surface reflects. The values of $\rho$ must be between 0 and 100 percent. In theory, any function on the interval [400, 700], that takes on values between 0 and 100 percent, can exist as a reflectance spectrum.

In practice, however, the actually occurring reflectance spectra, whether natural or man-made, are only a subset of the theoretically possible spectra. The term *real surface colours* denotes the set of actual spectra. In 1980, the Pointer gamut [3] was introduced, as an empirical delineation of the real surface colours. The Pointer gamut was derived from a comprehensive set of 4089 physical samples of surface colours. A colorimeter, which returned results relative to Illuminant C and the 1931 Standard Observer, was used to measure each sample, and CIE $L^*a^*b^*$ coordinates [6] were calculated. The samples thus produced a three-dimensional scatterplot in $L^*a^*b^*$ space. The points of the scatterplot can be enclosed by an approximating polyhedron. Table II of Pointer's 1980 paper describes the polyhedron in horizontal polygonal cross-sections corresponding to constant lightnesses ($L^*$). The table lists the vertices for each cross-section in terms of their chroma and hue correlates ($C^*_{ab}$ and $h_{ab}$), following around the hue circle. The polygonal sections are stacked into a polyhedron. The Pointer gamut consists of all surface colours whose $L^*a^*b^*$ coordinates are inside this polyhedron.

An important practical question is whether the Pointer gamut needs to be extended. While Pointer's 1980 paper incorporated a wide variety of sources, several new data sets have been compiled since then, most notably the International Standards Organization (ISO) Gamut of Surface Colours in 1998, and the ISO Reference Colour Gamut in 2007. In 2014, Li *et al.* [2] analysed the newer sets, in an attempt to update the Pointer gamut. While the newer gamuts exceeded the Pointer gamut in most regions of colour space, there were some inconsistencies and uncertainties. For instance, it was not known whether some of the reflectance spectra were absolute or relative. Also, some chromatic adaptation transforms were necessary, which are known to cause distortions at high chromas. Despite the wealth of measurements (about 90,000 spectra, in total), such issues prevented the authors from confidently recommending an updated gamut.

Given this uncertainty, it was decided to compare the pastel data only to the Pointer gamut. Pastels do not appear in Pointer's 1980 data, nor in any data sets since then. The 3154 spectra presented in this paper therefore represent new data, which other researchers are welcome to add to their databases, and use in further analysis. By maximising pigment concentration and minimising binder concentration, pastels can produce highly saturated colours, which are likely to appear as vertices in the real surface colour gamut. Later analysis, in fact, will show that pastels do extend the 1980 Pointer gamut in some places. Plausibly, however, some newer gamuts, which also seem to exceed the Pointer gamut, could already contain all the pastel colours.

### *The Pointer gamut in Munsell space*

Though originally presented in CIE coordinates, the Pointer gamut can be expressed more naturally in the Munsell system. Conveniently, the Pointer gamut assumed absolute reflectances, Illuminant C, and the 1931 2° Standard Observer – just the assumptions made by the 1943 Munsell renotation [4]. Every entry in Table II of Pointer's 1980 paper was therefore converted to Munsell coordinates. The conversion algorithm [5] failed for one entry, the value of 81 when $L^*$ is 30 and $h_{ab}$ is 300°. This entry appears on Figure 3 of the 1943 renotation paper, but outside the renotation curves; its Munsell coordinates were visually estimated to be 7.5PB 3/20. One minor clerical correction was made. The entry of 59 when $L^*$ is 70 and $h_{ab}$ is 180° appears as 60 on the website [11] of the Rochester Institute of Technology; the value of 60 was used here.

Table 3 presents the Pointer gamut in Munsell coordinates. It differs in two notable ways from Pointer's original Table II. First, the axis along the top gives the Munsell value V rather than $L^*$. Since V and $L^*$ are invertible functions of each other, there is no loss of information in this conversion. Furthermore, $L^*$ is almost exactly 10 times V; the difference is smaller than humans can discriminate. All values of V were therefore rounded to the nearest multiple of 0.5 for simplicity. Second, the new table contains no labels for the vertical axis, while Table II listed the hue angle $h_{ab}$ for this axis. The reason is that $h_{ab}$ only approximates human hue perception [12]. The entries in any one row of Table II have the same $h_{ab}$, but slightly different hues. Each entry of the Munsell table gives its hue explicitly; the hues in any one row vary slightly.

The data in Table 3 can be conveniently displayed as a set of gamut sections of constant Munsell value. The entries in the column under a particular Munsell value form an irregular polygon in a polar hue-chroma plot. Figure 5 shows an example for Munsell value 5.0. At the origin of the plot, chroma is 0 and hue is undefined, corresponding to N5.0. As the distance from the origin increases, chroma increases; colours of the same chroma lie on a circle centered on the origin. The polar angle corresponds to hue. All the colours of hue 0.0R, for example, are on the ray of polar angle 0° and colours of hue 10.0G are on the ray of polar angle 180°. If the entries in Table 3 in the column under value 5.0 are plotted and joined sequentially by lines, then the result is the polygon shown, the interior of which is the Pointer gamut for value 5.0. Since the $h_{ab}$ and $C^*_{ab}$ that Pointer used are rough approximations to Munsell hue and chroma, the Munsell polygons do not look noticeably different from Pointer's 1980 polygons.

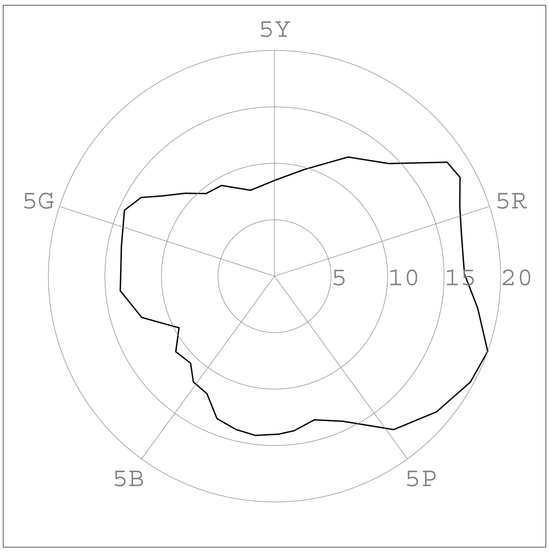


*Figure 5: The Pointer gamut in the Munsell system, at Munsell value 5.*

| Munsell values | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1.5** | **2** | **2.5** | **3** | **3.5** | **4** | **4.5** | **5** |
| 2.2R 1.5/1.6 | 1.0R 2.0/6.6 | 10.0RP 2.5/9.2 | 8.6RP 3.0/12.0 | 8.4RP 3.5/14.9 | 8.1RP 4.0/17.7 | 7.8RP 4.5/18.3 | 7.5RP 5.0/18.2 |
| 5.5R 1.5/2.6 | 3.9R 2.0/6.5 | 3.0R 2.5/9.4 | 1.4R 3.0/11.8 | 1.2R 3.5/13.7 | 0.9R 4.0/15.8 | 0.6R 4.5/16.5 | 0.2R 5.0/16.8 |
| 8.7R 1.5/2.3 | 6.7R 2.0/7.2 | 5.8R 2.5/10.0 | 4.4R 3.0/12.5 | 4.0R 3.5/14.4 | 3.6R 4.0/16.2 | 3.4R 4.5/16.6 | 3.2R 5.0/16.9 |
| 1.2YR 1.5/6.6 | 9.4R 2.0/9.7 | 8.5R 2.5/11.6 | 7.0R 3.0/13.5 | 6.6R 3.5/15.0 | 6.1R 4.0/17.2 | 5.8R 4.5/17.6 | 5.7R 5.0/17.5 |
| 3.2YR 1.5/4.5 | 1.5YR 2.0/7.7 | 0.7YR 2.5/9.9 | 9.5R 3.0/12.2 | 8.8R 3.5/14.8 | 8.1R 4.0/17.7 | 7.9R 4.5/18.6 | 7.8R 5.0/18.6 |
| 5.7YR 1.5/1.5 | 4.3YR 2.0/3.8 | 3.3YR 2.5/6.0 | 2.1YR 3.0/8.0 | 1.4YR 3.5/10.6 | 0.4YR 4.0/13.5 | 9.8R 4.5/16.3 | 9.3R 5.0/18.3 |
| 8.7YR 1.5/0.6 | 7.0YR 2.0/2.6 | 6.2YR 2.5/4.4 | 5.2YR 3.0/6.3 | 4.5YR 3.5/8.1 | 3.8YR 4.0/10.2 | 3.1YR 4.5/12.0 | 2.4YR 5.0/14.2 |
| 0.7Y 1.5/0.7 | 9.6YR 2.0/2.5 | 8.9YR 2.5/4.0 | 8.3YR 3.0/5.9 | 7.8YR 3.5/7.4 | 7.2YR 4.0/9.1 | 6.7YR 4.5/10.8 | 6.2YR 5.0/12.4 |
| 2.7Y 1.5/0.8 | 2.1Y 2.0/2.5 | 1.9Y 2.5/3.7 | 1.6Y 3.0/5.0 | 1.4Y 3.5/6.0 | 1.2Y 4.0/7.4 | 1.0Y 4.5/8.3 | 0.7Y 5.0/9.8 |
| 5.3Y 1.5/0.6 | 4.9Y 2.0/2.0 | 5.1Y 2.5/3.0 | 5.0Y 3.0/4.2 | 5.1Y 3.5/5.2 | 5.0Y 4.0/6.3 | 5.0Y 4.5/7.5 | 4.9Y 5.0/8.5 |
| 8.2Y 1.5/1.3 | 8.4Y 2.0/2.6 | 8.7Y 2.5/3.4 | 8.8Y 3.0/4.4 | 9.0Y 3.5/5.2 | 9.2Y 4.0/6.2 | 9.2Y 4.5/7.0 | 9.3Y 5.0/7.9 |
| 1.0GY 1.5/1.5 | 1.6GY 2.0/3.0 | 2.1GY 2.5/4.0 | 2.4GY 3.0/5.2 | 2.7GY 3.5/6.2 | 3.0GY 4.0/7.3 | 3.2GY 4.5/8.2 | 3.4GY 5.0/9.3 |
| 3.1GY 1.5/0.7 | 4.0GY 2.0/2.6 | 4.6GY 2.5/3.7 | 5.0GY 3.0/5.0 | 5.4GY 3.5/6.2 | 5.6GY 4.0/7.3 | 5.8GY 4.5/8.3 | 6.0GY 5.0/9.5 |
| 5.8GY 1.5/1.0 | 6.5GY 2.0/3.4 | 6.9GY 2.5/5.0 | 7.3GY 3.0/6.6 | 7.5GY 3.5/7.5 | 7.8GY 4.0/8.6 | 7.9GY 4.5/9.8 | 8.1GY 5.0/10.8 |
| 8.0GY 1.5/1.5 | 8.7GY 2.0/3.9 | 9.1GY 2.5/5.7 | 9.4GY 3.0/7.3 | 9.6GY 3.5/8.6 | 9.9GY 4.0/9.7 | 10.0GY 4.5/11.0 | 0.1G 5.0/12.2 |
| 0.6G 1.5/1.6 | 0.9G 2.0/4.2 | 1.1G 2.5/6.3 | 1.3G 3.0/8.3 | 1.3G 3.5/10.0 | 1.4G 4.0/11.6 | 1.4G 4.5/12.6 | 1.5G 5.0/13.7 |
| 3.9G 1.5/1.9 | 3.4G 2.0/4.9 | 3.2G 2.5/7.0 | 3.2G 3.0/9.1 | 3.2G 3.5/10.5 | 3.2G 4.0/11.9 | 3.3G 4.5/13.2 | 3.4G 5.0/14.5 |
| 7.3G 1.5/2.8 | 7.1G 2.0/5.4 | 6.9G 2.5/7.3 | 6.7G 3.0/9.3 | 6.6G 3.5/10.8 | 6.6G 4.0/11.8 | 6.8G 4.5/12.6 | 6.9G 5.0/13.8 |
| 0.9BG 1.5/2.3 | 0.8BG 2.0/5.6 | 0.8BG 2.5/7.9 | 0.9BG 3.0/9.9 | 1.0BG 3.5/11.2 | 1.1BG 4.0/12.2 | 1.3BG 4.5/13.1 | 1.5BG 5.0/13.7 |
| 3.4BG 1.5/1.7 | 3.6BG 2.0/4.5 | 3.8BG 2.5/6.6 | 4.0BG 3.0/8.5 | 4.1BG 3.5/9.8 | 4.4BG 4.0/11.0 | 4.6BG 4.5/11.6 | 4.8BG 5.0/12.3 |
| 5.5BG 1.5/1.2 | 6.0BG 2.0/4.6 | 6.3BG 2.5/6.5 | 6.8BG 3.0/8.1 | 7.0BG 3.5/8.8 | 7.3BG 4.0/9.3 | 7.6BG 4.5/9.5 | 7.9BG 5.0/9.6 |
| N1.5 | 8.5BG 2.0/3.0 | 8.8BG 2.5/3.8 | 9.2BG 3.0/5.7 | 9.5BG 3.5/7.3 | 9.8BG 4.0/9.2 | 0.0B 4.5/10.4 | 0.4B 5.0/11.0 |
| 9.8BG 1.5/0.5 | 0.9B 2.0/3.0 | 1.2B 2.5/4.5 | 1.6B 3.0/6.2 | 1.9B 3.5/7.7 | 2.2B 4.0/8.8 | 2.5B 4.5/9.8 | 2.8B 5.0/10.7 |
| 3.3B 1.5/2.2 | 3.4B 2.0/4.8 | 3.5B 2.5/6.6 | 3.8B 3.0/8.2 | 4.0B 3.5/9.4 | 4.3B 4.0/10.5 | 4.4B 4.5/11.2 | 4.6B 5.0/11.8 |
| 6.0B 1.5/1.7 | 6.0B 2.0/3.8 | 5.8B 2.5/5.9 | 5.9B 3.0/7.8 | 6.0B 3.5/9.4 | 6.2B 4.0/11.2 | 6.4B 4.5/11.7 | 6.7B 5.0/12.0 |
| 8.4B 1.5/1.9 | 8.0B 2.0/5.0 | 7.8B 2.5/7.3 | 8.0B 3.0/9.4 | 8.1B 3.5/11.6 | 8.4B 4.0/13.2 | 8.6B 4.5/13.4 | 8.9B 5.0/13.6 |
| 0.5PB 1.5/2.5 | 0.3PB 2.0/5.6 | 0.3PB 2.5/7.7 | 0.4PB 3.0/9.7 | 0.5PB 3.5/11.0 | 0.7PB 4.0/12.6 | 0.9PB 4.5/13.6 | 1.1PB 5.0/14.0 |
| 2.7PB 1.5/2.9 | 2.2PB 2.0/7.1 | 2.0PB 2.5/9.5 | 2.2PB 3.0/11.8 | 2.3PB 3.5/13.1 | 2.5PB 4.0/14.8 | 2.7PB 4.5/14.8 | 3.1PB 5.0/14.2 |
| 5.2PB 1.5/1.9 | 4.9PB 2.0/6.4 | 4.3PB 2.5/10.0 | 4.3PB 3.0/12.7 | 4.5PB 3.5/14.0 | 4.9PB 4.0/14.7 | 5.2PB 4.5/14.5 | 5.4PB 5.0/14.0 |
| 6.7PB 1.5/3.9 | 6.0PB 2.0/8.6 | 5.5PB 2.5/13.1 | 5.6PB 3.0/15.4 | 5.8PB 3.5/16.0 | 6.2PB 4.0/16.1 | 6.6PB 4.5/15.2 | 7.0PB 5.0/13.8 |
| 8.2PB 1.5/5.8 | 7.1PB 2.0/11.7 | 6.7PB 2.5/15.2 | 7.5PB 3.0/20.0 | 7.3PB 3.5/17.2 | 8.1PB 4.0/16.2 | 8.8PB 4.5/14.5 | 9.3PB 5.0/13.2 |
| 8.8PB 1.5/12.8 | 8.8PB 2.0/16.4 | 8.9PB 2.5/18.0 | 9.4PB 3.0/19.0 | 0.1P 3.5/18.5 | 0.8P 4.0/17.9 | 1.4P 4.5/16.0 | 2.0P 5.0/14.2 |
| 3.6P 1.5/12.4 | 3.7P 2.0/15.3 | 3.9P 2.5/16.7 | 4.2P 3.0/18.1 | 4.5P 3.5/18.5 | 4.8P 4.0/19.3 | 5.2P 4.5/18.6 | 5.5P 5.0/17.2 |
| 1.1RP 1.5/3.6 | 0.1RP 2.0/10.8 | 9.8P 2.5/15.2 | 9.4P 3.0/18.6 | 9.2P 3.5/19.5 | 9.0P 4.0/20.0 | 9.0P 4.5/19.5 | 8.9P 5.0/18.7 |
| 5.2RP 1.5/5.1 | 4.0RP 2.0/10.8 | 3.4RP 2.5/13.5 | 2.8RP 3.0/15.9 | 2.7RP 3.5/18.1 | 2.5RP 4.0/19.8 | 2.3RP 4.5/20.0 | 2.1RP 5.0/19.7 |
| 9.0RP 1.5/2.6 | 7.6RP 2.0/8.1 | 6.9RP 2.5/11.2 | 5.9RP 3.0/14.2 | 5.6RP 3.5/16.2 | 5.2RP 4.0/18.3 | 4.9RP 4.5/19.1 | 4.6RP 5.0/20.0 |

*Table 3: The Pointer gamut in Munsell coordinates.*

| Munsell values | | | | | | | |
|---|---|---|---|---|---|---|---|
| **5.5** | **6** | **6.5** | **7** | **7.5** | **8** | **8.5** | **9** |
| 7.2RP 5.5/17.1 | 6.9RP 6.0/15.6 | 6.6RP 6.5/13.7 | 6.4RP 7.0/12.1 | 6.1RP 7.5/9.8 | 5.8RP 8.0/7.4 | 5.6RP 8.5/4.9 | 5.3RP 9.0/2.6 |
| 9.9RP 5.5/16.4 | 9.6RP 6.0/15.3 | 9.4RP 6.5/13.5 | 9.1RP 7.0/11.4 | 8.9RP 7.5/9.4 | 8.8RP 8.0/7.3 | 8.5RP 8.5/4.6 | 8.2RP 9.0/2.3 |
| 3.0R 5.5/16.5 | 2.7R 6.0/15.5 | 2.4R 6.5/13.9 | 2.1R 7.0/11.7 | 2.0R 7.5/9.2 | 1.9R 8.0/7.0 | 1.7R 8.5/4.6 | 1.7R 9.0/2.6 |
| 5.6R 5.5/17.0 | 5.5R 6.0/16.2 | 5.5R 6.5/14.4 | 5.4R 7.0/12.1 | 5.4R 7.5/9.7 | 5.3R 8.0/7.2 | 5.1R 8.5/4.7 | 5.0R 9.0/2.6 |
| 7.8R 5.5/17.6 | 7.8R 6.0/16.6 | 7.9R 6.5/14.5 | 8.1R 7.0/12.1 | 8.2R 7.5/9.5 | 8.2R 8.0/7.1 | 8.2R 8.5/4.5 | 8.1R 9.0/2.4 |
| 9.3R 5.5/18.8 | 9.4R 6.0/18.4 | 9.8R 6.5/16.4 | 0.2YR 7.0/14.0 | 0.7YR 7.5/11.1 | 0.8YR 8.0/8.5 | 0.9YR 8.5/5.6 | 1.0YR 9.0/3.0 |
| 2.0YR 5.5/16.2 | 1.6YR 6.0/17.8 | 1.7YR 6.5/18.5 | 2.2YR 7.0/17.3 | 2.8YR 7.5/14.8 | 3.3YR 8.0/11.6 | 3.6YR 8.5/7.8 | 3.6YR 9.0/4.0 |
| 5.9YR 5.5/13.9 | 5.5YR 6.0/15.4 | 5.2YR 6.5/16.8 | 5.1YR 7.0/17.9 | 5.4YR 7.5/17.2 | 6.1YR 8.0/13.6 | 6.5YR 8.5/9.6 | 6.3YR 9.0/5.5 |
| 0.4Y 5.5/11.0 | 0.2Y 6.0/12.6 | 9.8YR 6.5/14.4 | 9.5YR 7.0/16.1 | 9.3YR 7.5/17.7 | 9.3YR 8.0/17.8 | 9.8YR 8.5/12.9 | 9.5YR 9.0/7.3 |
| 4.8Y 5.5/9.7 | 4.6Y 6.0/10.8 | 4.5Y 6.5/11.9 | 4.4Y 7.0/13.0 | 4.3Y 7.5/14.1 | 4.2Y 8.0/15.3 | 4.0Y 8.5/15.9 | 3.7Y 9.0/12.9 |
| 9.4Y 5.5/8.8 | 9.5Y 6.0/9.8 | 9.7Y 6.5/10.9 | 9.7Y 7.0/11.7 | 9.8Y 7.5/12.8 | 9.8Y 8.0/13.7 | 9.9Y 8.5/14.4 | 9.7Y 9.0/14.6 |
| 3.6GY 5.5/10.3 | 3.9GY 6.0/11.5 | 3.9GY 6.5/12.1 | 4.0GY 7.0/12.8 | 4.0GY 7.5/13.1 | 4.1GY 8.0/13.7 | 3.9GY 8.5/13.0 | 3.4GY 9.0/11.2 |
| 6.1GY 5.5/10.4 | 6.3GY 6.0/11.5 | 6.4GY 6.5/12.4 | 6.5GY 7.0/13.3 | 6.5GY 7.5/13.7 | 6.5GY 8.0/13.7 | 6.3GY 8.5/11.7 | 5.9GY 9.0/6.6 |
| 8.2GY 5.5/11.9 | 8.3GY 6.0/12.8 | 8.4GY 6.5/13.2 | 8.4GY 7.0/13.7 | 8.4GY 7.5/13.7 | 8.4GY 8.0/12.8 | 8.2GY 8.5/9.3 | 7.9GY 9.0/4.6 |
| 0.1G 5.5/13.2 | 0.2G 6.0/14.1 | 0.3G 6.5/14.4 | 0.3G 7.0/14.8 | 0.4G 7.5/13.5 | 0.4G 8.0/11.4 | 0.3G 8.5/8.3 | 0.3G 9.0/4.2 |
| 1.5G 5.5/14.2 | 1.7G 6.0/14.3 | 1.8G 6.5/14.2 | 2.0G 7.0/13.8 | 2.1G 7.5/12.2 | 2.3G 8.0/9.7 | 2.4G 8.5/6.9 | 2.5G 9.0/2.8 |
| 3.5G 5.5/15.1 | 3.8G 6.0/15.0 | 4.0G 6.5/14.1 | 4.3G 7.0/12.4 | 4.6G 7.5/10.5 | 4.8G 8.0/8.5 | 5.2G 8.5/5.5 | 5.9G 9.0/2.2 |
| 7.1G 5.5/14.1 | 7.4G 6.0/14.1 | 7.8G 6.5/13.3 | 8.3G 7.0/12.3 | 8.6G 7.5/10.7 | 9.1G 8.0/8.3 | 9.6G 8.5/5.2 | 0.2BG 9.0/2.4 |
| 1.7BG 5.5/14.0 | 2.0BG 6.0/13.6 | 2.3BG 6.5/12.6 | 2.6BG 7.0/11.9 | 2.9BG 7.5/10.0 | 3.3BG 8.0/7.9 | 3.8BG 8.5/5.3 | 4.4BG 9.0/2.7 |
| 5.0BG 5.5/12.4 | 5.3BG 6.0/12.3 | 5.6BG 6.5/11.3 | 5.9BG 7.0/10.1 | 6.2BG 7.5/8.4 | 6.5BG 8.0/6.4 | 6.9BG 8.5/4.4 | 7.2BG 9.0/2.4 |
| 8.1BG 5.5/9.4 | 8.3BG 6.0/9.2 | 8.6BG 6.5/8.3 | 8.9BG 7.0/7.6 | 9.2BG 7.5/6.4 | 9.6BG 8.0/4.5 | 10.0BG 8.5/2.8 | 0.3B 9.0/1.4 |
| 0.6B 5.5/11.6 | 0.9B 6.0/11.0 | 1.1B 6.5/10.1 | 1.4B 7.0/8.9 | 1.8B 7.5/7.0 | 2.4B 8.0/5.2 | 2.7B 8.5/3.0 | 2.8B 9.0/0.9 |
| 2.9B 5.5/11.4 | 3.1B 6.0/11.2 | 3.4B 6.5/10.3 | 3.7B 7.0/8.7 | 4.0B 7.5/7.3 | 4.5B 8.0/5.2 | 4.8B 8.5/3.4 | 5.1B 9.0/1.5 |
| 4.8B 5.5/12.1 | 4.9B 6.0/11.8 | 5.2B 6.5/10.6 | 5.7B 7.0/9.2 | 6.2B 7.5/7.5 | 6.8B 8.0/5.7 | 7.4B 8.5/3.6 | 7.7B 9.0/2.0 |
| 6.9B 5.5/12.0 | 7.2B 6.0/11.4 | 7.5B 6.5/10.2 | 8.1B 7.0/8.8 | 8.6B 7.5/7.1 | 9.1B 8.0/5.2 | 9.6B 8.5/3.1 | 0.2PB 9.0/1.2 |
| 9.2B 5.5/12.8 | 9.5B 6.0/11.9 | 9.8B 6.5/10.7 | 0.2PB 7.0/9.0 | 0.6PB 7.5/7.3 | 1.0PB 8.0/5.4 | 1.4PB 8.5/3.5 | 1.7PB 9.0/1.4 |
| 1.3PB 5.5/12.7 | 1.6PB 6.0/11.6 | 1.9PB 6.5/10.1 | 2.3PB 7.0/8.5 | 2.6PB 7.5/6.9 | 3.0PB 8.0/5.2 | 3.2PB 8.5/3.5 | 3.6PB 9.0/2.1 |
| 3.6PB 5.5/12.4 | 3.9PB 6.0/11.3 | 4.2PB 6.5/9.8 | 4.5PB 7.0/8.4 | 4.9PB 7.5/6.7 | 5.1PB 8.0/5.2 | 5.2PB 8.5/3.6 | 5.5PB 9.0/2.1 |
| 5.6PB 5.5/13.0 | 5.9PB 6.0/11.4 | 6.1PB 6.5/10.0 | 6.3PB 7.0/8.5 | 6.7PB 7.5/6.3 | 6.9PB 8.0/4.8 | 7.1PB 8.5/3.2 | 7.2PB 9.0/1.5 |
| 7.4PB 5.5/11.9 | 7.7PB 6.0/10.5 | 8.1PB 6.5/8.8 | 8.4PB 7.0/7.2 | 8.8PB 7.5/6.0 | 9.0PB 8.0/4.7 | 9.2PB 8.5/3.4 | 9.2PB 9.0/1.9 |
| 9.7PB 5.5/11.7 | 0.2P 6.0/10.1 | 0.6P 6.5/8.5 | 0.9P 7.0/7.4 | 1.3P 7.5/6.0 | 1.6P 8.0/4.5 | 1.8P 8.5/3.3 | 2.0P 9.0/1.8 |
| 2.5P 5.5/12.7 | 3.0P 6.0/11.1 | 3.4P 6.5/9.7 | 3.8P 7.0/8.3 | 4.2P 7.5/6.7 | 4.6P 8.0/5.2 | 5.0P 8.5/3.7 | 5.2P 9.0/2.1 |
| 5.8P 5.5/15.4 | 6.0P 6.0/13.5 | 6.2P 6.5/11.5 | 6.3P 7.0/9.7 | 6.4P 7.5/7.7 | 6.5P 8.0/6.2 | 6.5P 8.5/4.3 | 6.6P 9.0/2.6 |
| 8.9P 5.5/17.0 | 8.9P 6.0/15.1 | 8.8P 6.5/13.0 | 8.8P 7.0/11.0 | 8.7P 7.5/8.8 | 8.6P 8.0/6.9 | 8.5P 8.5/4.8 | 8.3P 9.0/2.8 |
| 2.0RP 5.5/18.6 | 1.8RP 6.0/17.2 | 1.7RP 6.5/15.0 | 1.5RP 7.0/12.5 | 1.3RP 7.5/9.8 | 1.1RP 8.0/7.1 | 1.0RP 8.5/4.8 | 0.6RP 9.0/1.6 |
| 4.4RP 5.5/18.9 | 4.2RP 6.0/17.8 | 4.0RP 6.5/15.3 | 3.8RP 7.0/13.0 | 3.6RP 7.5/9.9 | 3.4RP 8.0/7.5 | 3.2RP 8.5/4.6 | 3.1RP 9.0/2.2 |

*Table 3 (cont'd): The Pointer gamut in Munsell coordinates.*

## Comparing the pastel gamut and the Pointer gamut

As mentioned earlier, pastels' high pigment loads can produce highly saturated colours. Since pastels cannot be mixed like paints, pastel makers also create fine gradations of hues. These two facts suggest that pastels should cover a wide gamut. This section compares the pastel gamut to the Pointer gamut. The comparison will show that pastels fill most of the Pointer gamut, leaving only a few gaps. In addition, however, 67 pastels lie outside the Pointer gamut, most notably in yellows and blue-purples of Munsell values lighter than 7. These outliers suggest that the Pointer gamut can be extended.

The previous section expressed the Pointer gamut as a set of polygonal cross-sections at constant Munsell values. In Table 3, those values range from 1.5 to 9.0, in steps of 0.5. The sections were computed by collecting samples of similar Munsell value (or equivalently, $L^*$) into one bin, projecting that bin onto a polar hue-chroma plot, and finding the projection's polygonal boundary on that plot. To compare the pastel and Pointer gamuts, the pastel colours were similarly binned by Munsell value. For instance, all the colours whose Munsell values were between 6.75 and 7.25 were assembled into one bin, that was compared with the section of the Pointer gamut at Munsell value 7.0. Similar bins of width 0.5 were created around the other Munsell values in Table 3. Two exceptions were the bounding values of 1.5 and 9.0; to include all the data, the bins around these values extended from 0.0 to 1.75, and from 8.75 to 10.0.

Figures 6 and 7 compare the pastel colours to the Pointer gamut directly, section by section. Each graph in the figures presents both a scatterplot of pastel colours, and the Pointer polygon for that Munsell value. Having been binned by value, the colours in the scatterplot (except for the first and last graph) are all within 0.25 value steps of the indicated Munsell value; the colours are therefore plotted only by hue and chroma. If a point is inside the polygon, then the pastel represented by that point is contained in the Pointer gamut. If a point is outside the polygon, then the pastel is outside the Pointer gamut, so the gamut would have to be extended to include it.

Table 4 lists the pastels, 67 in all, that are outside the polygons. Eight of them occur in the graph for Munsell value 1.5. The irregular spikes in the polygon, combined with the fact that the Pointer gamut was not defined for Munsell value 1, suggest that the original Pointer data was sparse for such very dark colours. Continuing along the graphs in the figure, we see two pastels, Sennelier 389 and Great American 340.0, that are clearly outside the polygons for values 4.0 and 4.5. Apart from these two pastels, the table lists three others, from values 2.0 to 7.0 inclusive, that are technically outside, but are so close to the boundary that they can be neglected. Above value 7.0, however, many pastels are definitely outside the polygons, extending the Pointer gamut for lighter colours. The graph for value 9.0, in particular, shows many new saturated yellows. Besides the yellows, the graphs in the bottom row show that most of the extension occurs in the blue-purple region.

Highly chromatic colours determine the boundaries of the real surface colour gamut, and are thus of more interest than dull colours. Indeed, the colours of lesser chroma could be largely disregarded, reducing data sets by one or two orders of magnitude. The Pointer gamut could be readily extended by combining the 67 colours in Table 4 with the high-chroma colours in the Pointer data set (assuming those colours are known). Since pastel measurements are rather variable, it would be helpful for other researchers to verify the reflectance spectra for Table 4. All the pastels listed are available commercially, costing between $4 and $6 US apiece, so samples could be remade and re-measured independently, which would be of general help in establishing the real surface colour gamut.

Ideally, the entire real surface colour gamut would be available to pastelists. Figures 6 and 7 show that pastels achieve this goal very well for lighter values, where the points of the scatterplot fill most of the Pointer polygons, and often exceed them. All but the highest values, however, show a lack of high-chroma pastels for the greens and blue-greens; the polygons in this hue region are not well filled. Values of 5.0 and below show a similar shortage in the reddish purples. In the very dark values, below 3.0, pastels are generally sparse over many hue regions. Overall, despite these gaps, pastel colours do a creditable job of providing a very wide colour gamut for artists.

| Brand | Identifier | Munsell | Brand | Identifier | Munsell |
|---|---|---|---|---|---|
| Sennelier | 57 | 1.14Y 1.60/0.76 | Schmincke | 650O | 4.68B 8.43/3.45 |
| Sennelier | 133 | 3.67PB 1.72/3.25 | Great American | 470.5 | 4.11PB 8.35/4.24 |
| Sennelier | 412 | 7.50YR 1.70/1.46 | Great American | 690.5 | 0.85RP 8.52/5.38 |
| Sennelier | 456 | 8.09YR 1.68/1.63 | Great American | 700.5 | 0.43RP 8.33/5.19 |
| Sennelier | 463 | 4.89PB 1.07/2.58 | Great American | 720.6 | 3.21P 8.45/4.00 |
| Sennelier | 465 | 5.40PB 1.10/3.96 | Great American | 750.5 | 5.51P 8.29/4.41 |
| Schmincke | 066B | 6.67PB 1.32/5.66 | Great American | 945.4 | 2.60B 8.55/3.61 |
| Schmincke | 066D | 6.74PB 1.44/5.69 | Mount Vision | 84 | 0.39PB 8.35/5.09 |
| Girault | 287 | 1.37PB 2.14/6.37 | Mount Vision | 223 | 1.86PB 8.50/3.93 |
| Girault | 259 | 9.17BG 2.66/3.93 | Mount Vision | 433 | 0.18PB 8.42/3.39 |
| Sennelier | 389 | 6.98PB 3.90/16.89 | Mount Vision | 786 | 2.35P 8.36/4.49 |
| Great American | 340.0 | 7.19PB 4.35/16.46 | Sennelier | 97 | 4.89Y 8.78/14.57 |
| Sennelier | 390 | 6.60PB 5.03/13.92 | Sennelier | 98 | 5.33Y 8.86/14.46 |
| Unison | BV10 | 6.55PB 5.92/11.15 | Sennelier | 198 | 5.91Y 8.89/13.51 |
| Blue Earth | B5A | 4.62PB 7.25/7.10 | Sennelier | 602 | 0.12GY 9.26/15.85 |
| Great American | 470.3 | 4.80PB 7.31/7.34 | Unison | Light7 | 8.62R 8.77/2.80 |
| Mount Vision | 83 | 1.32PB 7.51/7.22 | Schmincke | 002D | 0.26GY 9.25/15.39 |
| Unison | T6 | 2.57B 7.79/5.54 | Schmincke | 003D | 6.16Y 9.01/14.27 |
| Great American | 310.0 | 8.26B 7.92/5.53 | Schmincke | 003H | 7.30Y 9.15/13.97 |
| Great American | 470.4 | 4.60PB 7.87/5.76 | Schmincke | 008D | 7.89Y 9.15/17.42 |
| Great American | 590.4 | 0.41YR 7.77/8.44 | Great American | 100.6 | 0.83YR 8.75/2.96 |
| Great American | 690.4 | 0.58RP 7.94/7.22 | Great American | 350.0 | 4.22Y 8.77/13.32 |
| Great American | 720.5 | 3.52P 7.87/5.42 | Great American | 590.6 | 2.19YR 8.88/4.32 |
| Great American | 945.3 | 2.52B 7.96/5.21 | Great American | 915.7 | 0.77YR 8.81/2.97 |
| Mount Vision | 523 | 5.74PB 7.94/5.16 | Great American | 945.5 | 2.28B 8.80/3.02 |
| Mount Vision | 765 | 6.99PB 7.92/5.09 | Great American | 945.6 | 0.96B 9.09/2.08 |
| Sennelier | 298 | 0.97Y 8.27/15.39 | Mount Vision | 24 | 2.00RP 9.15/3.03 |
| Sennelier | 734 | 2.14B 8.27/3.97 | Mount Vision | 25 | 1.80RP 9.31/3.14 |
| Sennelier | 745 | 1.20B 8.41/3.57 | Mount Vision | 224 | 9.86B 9.15/2.34 |
| Blue Earth | B7A | 3.87PB 8.51/3.75 | Mount Vision | 242 | 2.93RP 8.89/3.64 |
| Schmincke | 042O | 9.05R 8.44/5.34 | Mount Vision | 243 | 2.37RP 9.33/2.91 |
| Schmincke | 044O | 3.91R 8.36/5.21 | Mount Vision | 434 | 5.78B 9.12/2.10 |
| Schmincke | 065O | 4.78B 8.40/3.45 | Mount Vision | 524 | 4.37PB 8.84/2.58 |
| Schmincke | 072O | 3.31G 8.30/6.43 | | | |

*Table 4: Pastels that are outside the Pointer gamut.*

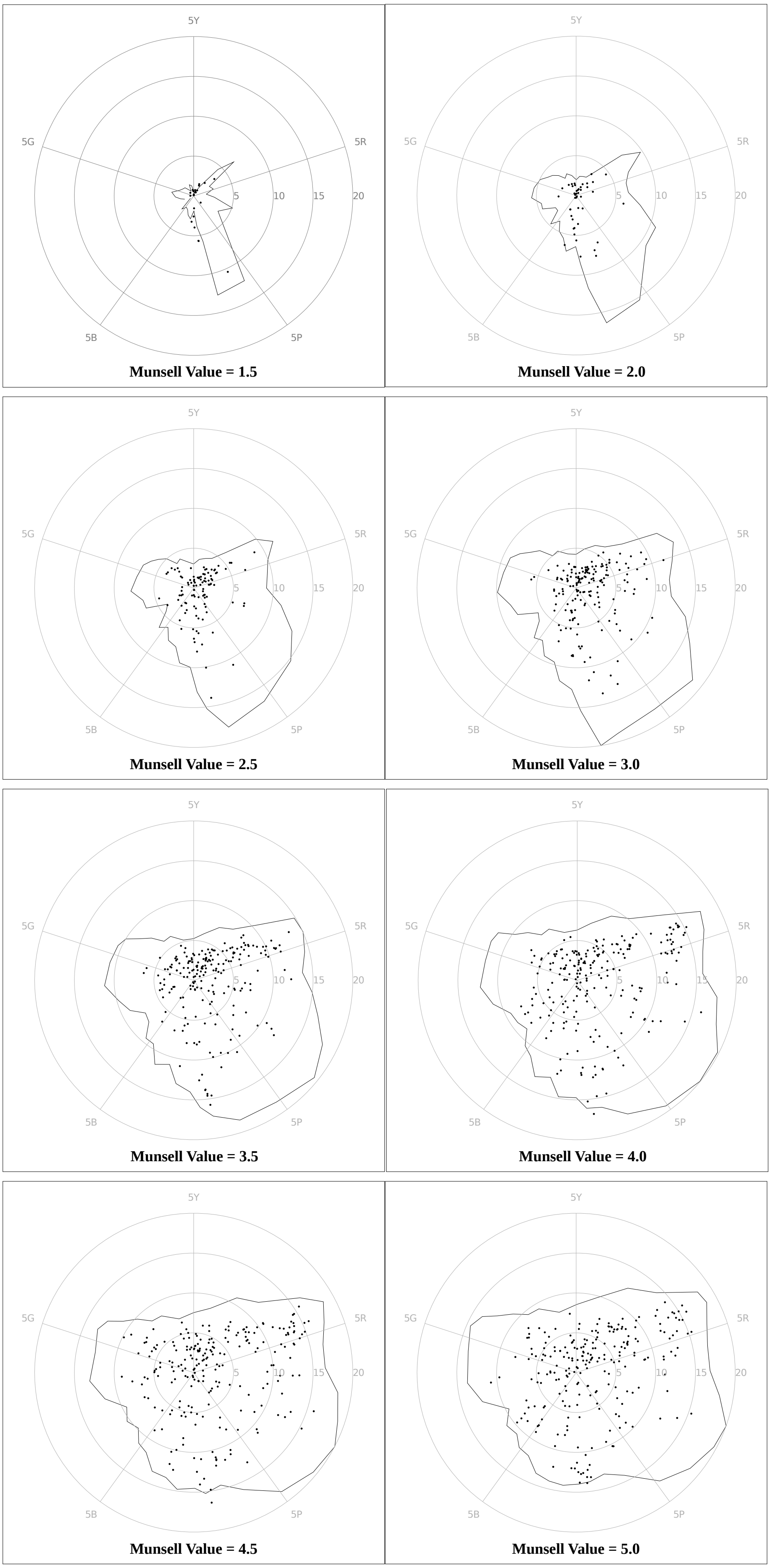


*Figure 6: Comparison of pastel colours with Pointer gamut (Munsell value ≤ 5).*

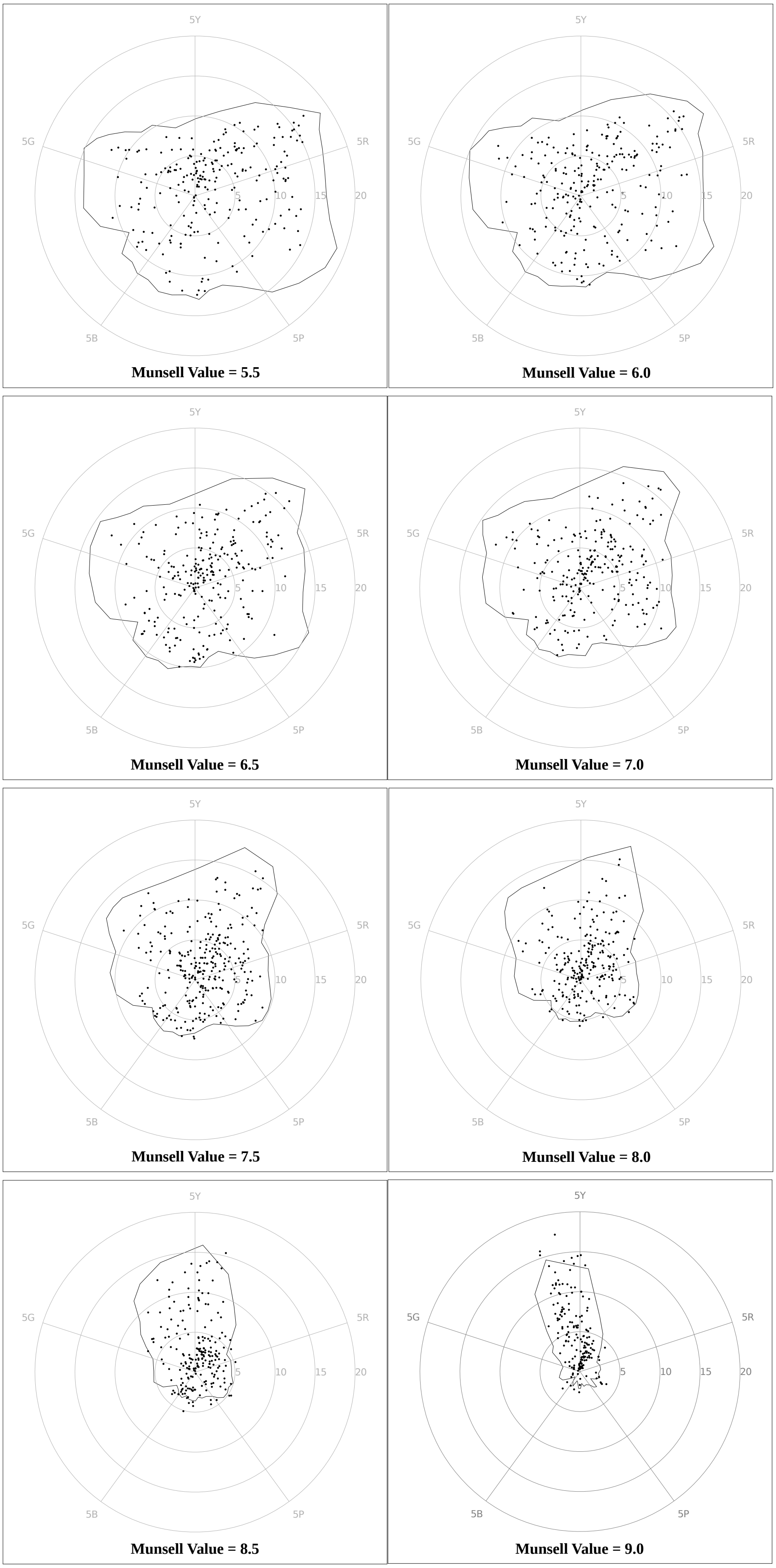


*Figure 7: Comparison of pastel colours with Pointer gamut (Munsell value > 5).*

## Data files and spreadsheets

To allow others to analyse pastel data further, some measured and calculated values have been posted online as text files or spreadsheets. They appear alongside this article on the JAIC website, as components of the single file DataFilesForPastelColourSurvey.zip. Each component file contains tab-delimited, human-readable text, in a matrix format. The first line is a header row, that describes the contents of the rows beneath. The files can be easily opened in spreadsheet programs such as Microsoft Excel, or read in by programming languages such as C or Matlab. For convenience, two workbooks, one in Microsoft Excel .xls format and one in NeoOffce .ods format, have also been provided. Multiple text files appear as spreadsheets in these two workbooks.

The following files have been provided:

(1) **ReflectanceSpectraForPastels.txt**. Each row of this text file gives the reflectance fraction, expressed as a decimal number between 0 and 1, of one pastel. Reflectance fractions are given for wavelengths between 380 and 730 nm, in increments of 10 nm.

(2) **MunsellDataForPastels.txt**. Each row of this text file gives the Munsell coordinates for one pastel. In addition to the complete Munsell specification, columns give particular parts of the Munsell specification. For example, there are columns for value and chroma. One column, ASTM hue, gives hue as a number between 0 and 100 (except neutrals, which are assigned a value of NaN), in accordance with Figure 1 of the ASTM Munsell specification standard [13].

(3) **CIEDataC2ForPastels.txt**. CIE coordinates ($X$, $Y$, $Z$, $x$, $y$, $L^*$, $a^*$, $b^*$, $C^*$, $h$) are given for each pastel. The CIE coordinates have been calculated with respect to C/2 viewing conditions, for consistency with the Munsell renotation and the Pointer gamut.

(4) **NearDuplicatesForPastels.txt**. This file lists all pairs of pastels that are produced by the same manufacturer, and that differ by 2 $\Delta E_{00}$ units or less.

(5) **MunsellToPastel.txt**. This file is a kind of inverse to MunsellDataForPastels.txt. Given a Munsell specification from the renotation, the file lists those pastels that are the best match for it.

(6) **PastelData.ods** and **PastelData.xls**. Each of the five preceding files appears as one spreadsheet in these two workbooks.

(7) **PointerGamutInMunsellSpace.txt/.ods/.xls**. These files give the bounding vertices of the Pointer gamut as Munsell specifications, taken from Table 3.

The spreadsheets can be easily manipulated for analysis. Suppose, for example, that one wants to find the most saturated pastels. Then open PastelData.ods or PastelData.xls to the spreadsheet "Munsell". Table 5 shows the first few lines. Saturation corresponds to chroma, which occurs in the final column. Highlight all the columns that contain entries. Click on Data, on the upper bar of the spreadsheet. A drop-down menu will appear, from which the option Sort should be selected. This option leaves individual rows untouched, but reorders them so that the entries of a user-specified column are sorted. Choose the column labelled Chroma, and specify that the order is Descending, to make the highest chromas appear first.

Table 6 shows the first few lines of the newly ordered data, with the most saturated pastels at the top. The rightmost column shows the highest chromas achieved, over the entire data set of 3154 pastels. The most intense pastels therefore reach Munsell chromas of about 17. The bottom of the file would show the dullest pastels, those that are nearest to neutral. By selecting Ascending rather than Descending order, the dullest pastels would appear at the top of the list, and the most saturated pastels at the bottom. The sorting technique is very versatile. For example, the pastels from one brand could all be grouped together by sorting on Brand, or all the pastels could be arranged in a rainbow by sorting on ASTM Hue.

| Brand | Identifier | Munsell specification | Total hue | Hue prefix | Hue letter(s) | ASTM | Value | Chroma |
|---|---|---|---|---|---|---|---|---|
| Blue Earth | B1A | 6.82PB 3.14/9.34 | 6.82PB | 6.82 | PB | 76.82 | 3.14 | 9.34 |
| Blue Earth | B2A | 6.55PB 3.20/7.35 | 6.55PB | 6.55 | PB | 76.55 | 3.20 | 7.35 |
| Blue Earth | B3A | 6.75PB 2.35/2.57 | 6.75PB | 6.75 | PB | 76.75 | 2.35 | 2.57 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |

*Table 5: The spreadsheet "Munsell" in the file PastelData.ods.*

| Brand | Identifier | Munsell specification | Total hue | Hue prefix | Hue letter(s) | ASTM | Value | Chroma |
|---|---|---|---|---|---|---|---|---|
| Schmincke | 008D | 7.89Y 9.15/17.42 | 7.89Y | 7.89 | Y | 27.89 | 9.15 | 17.42 |
| Sennelier | 389 | 6.98PB 3.90/16.89 | 6.98PB | 6.98 | PB | 76.98 | 3.90 | 16.89 |
| Sennelier | 930 | 0.13YR 5.54/16.85 | 0.13YR | 0.13 | YR | 10.13 | 5.54 | 16.85 |
| Great American | 340.0 | 7.19PB 4.35/16.46 | 7.19PB | 7.19 | PB | 77.19 | 4.35 | 16.46 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |

*Table 6: The spreadsheet "Munsell", ordered from highest chroma to lowest.*

The spreadsheet "MunsellToPastel" presents a sort of inverse table (see Table 7), which should be of particular interest to painters, because it helps find a pastel that is a good match for a desired colour. Suppose a pastelist wants a certain colour, such as 7.5RP 5/8. Then the row for 7.5RP 5/8 in "MunsellToPastel" gives the closest available pastel as Girault 328, whose DE from 7.5RP 5/8 is 1.6, a good match. The next best match is Schmincke 034O, with a DE of 3.9. Three other possible matches, with their DEs, are also given.

| Munsell | ... | 1. Brand | 1. Identifier | 1. DE00 | 2. Brand | 2. Identifier | 2. DE00 | ... |
|---|---|---|---|---|---|---|---|---|
| 7.5RP 5/8 | ... | Girault | 328 | 1.6 | Schmincke | 034O | 3.9 | ... |

*Table 7: Best pastel matches for 7.5RP 5/8, from the spreadsheet "MunsellToPastel".*

## Summary

This paper has presented a colour survey of 3154 artist's pastels. The paper's starting point consisted of original measurements of all the pastels' reflectance spectra. Munsell specifications and

CIE coordinates (relative to C/2) were calculated from the spectra. The range of pastel colours was analysed in terms of the Pointer gamut, after converting that gamut to Munsell space. Artist's pastels cover the Pointer gamut well in most regions, and in fact exceed it for light blue-purples and very light yellow, suggesting that it can be extended. The pastels' reflectance spectra, the Munsell coordinates for the Pointer gamut, and the results of various calculations have all been posted along with this paper, as both text files and spreadsheets. Other researchers are free to use this data for further analysis, and to combine it with data of their own. An interesting open problem is to delineate the real colour gamut; since pastel measurements have not been publicly available before, and since pastels span a considerable gamut, the data should be relevant to this problem.

## References


1. Mayer R (1991), *The Artist's Handbook of Materials and Techniques*, 5th edition, Faber & Faber.
2. Li C, Luo MR, Pointer MR and Green P (2014), Comparison of real colour gamuts using a new reflectance database, *Color Research and Application*, **39** (5), 442-451.
3. Pointer MR (1980), The gamut of real surface colours, *Color Research and Application*, **5** (3), 145-155.
4. Newhall S, Nickerson D and Judd DB (1943), Final report of the O.S.A. subcommittee on the spacing of the Munsell colors, *Journal of the Optical Society of America*, **33** (7), 385-418.
5. Centore P (2012), An open-source inversion algorithm for the Munsell renotation, *Color Research and Application*, **37** (6), 455-464.
6. CIE (2004), *Colorimetry*, Vienna: CIE Technical Report No. 15:2004, 3rd edition, Central Bureau of the CIE.
7. Meyer M (2008), *Multi-Brand Color Chart: Pastels*, Huechroval Corporation.
8. Berns RS (2000), *Billmeyer and Saltzman's Principles of Color Technology*, 3rd edition, John Wiley & Sons.
9. Sharma G, Wu W and Dalal EN (2005), The CIEDE2000 formula: Implementation notes, supplementary test data, and mathematical observations, *Color Research and Application*, **30** (1), 21-30.
10. Centore P, The coeffient of variation as a measure of spectrophotometric repeatability, accepted for *Color Research and Application*.
11. https://www.rit.edu/cos/colorscience/rc_useful_data.php – last accessed 5 May 2016.
12. Fairchild MD (2005), *Color Appearance Models*, 2nd edition, John Wiley & Sons.
13. ASTM (2008), ASTM Standard D 1535-08: Standard practice for specifying color by the Munsell system.