Computational color analysis of paintings for different artists of the XVI and XVII centuries

Authors: Javier Romero, Luis Gómez-Robledo and Juan Luis Nieves

Departarmento de Óptica. Facultad de Ciencias Universidad de Granada 18071 Granada. Spain

Keywords

Color in Art; Image analysis; Color of paintings; Discernible colors; Chromatic diversity

Abstract

We have performed a computational color analysis of images of paintings for six master painters: Titian, Rubens, El Greco, Velázquez, Rembrandt and Vermeer. These painters show the evolution from the renaissance to the baroque style. Different first and second-order statistical parameters have been obtained and analyzed in order to fix which of them can be common for the different artists and which of them can be representative of a certain period of time or the evolution of the art. The firsts include the orientation and semi-axes ratio of the ellipses that define the gamut in the chromaticity diagram and the dependencies with the frequency of the power of the Fourier transforms. Most differences among artists can be found in the volume and area of the gamut, the number of discernible colors which is greater for Titian, El Greco and Rubens, compared to Velázquez, Rembrandt and Vermeer, the average value of L* and the number of dark pixels.

Introduction

Painting is one of the artistic expressions of greater presence in the Society. Along the centuries, painters have translated the reality or have made an interpretation of it according to their subjective impression. In many cases, they can also to provoke feelings or thoughts on a theme whether religious, social or simply aesthetic. The different styles and techniques reflect each era, as shown in the books of Story of Art[1].

Graham and Field[2] determine the fractal dimension of paintings from the slope of the lines of variation of the logarithm of the power spectrum with the logarithm of the frequency, concluding that the paintings have a fractal dimension slightly higher than the natural scenes. The fractal dimension has been related to the perception of roughness and complexity, discrimination and aesthetic preference. Related to the calculation of the fractal dimension, Taylor et al.[3] have shown the potential of this statistical technique in the detection of falsifications. Specifically, these authors found good results in distinguishing original from copies of Jackson Pollock's paintings[4]. Mureika[5] has also studied the fractal dimension of this author's paintings and their relationship with the principles of Aesthetics.

Other remarkable parameter has been studied is the distribution of luminosity in paintings. In natural scenes the dynamic range of luminance observed is much greater than that which can be achieved in paintings. If the former can range from 1000 to 1, the latter can be approximately 30 to 1[6]. The distributions of luminance in natural scenes are highly asymmetrical and, however, the same is not the case with those found in paintings[2,7,8]. These results suggest that painters perform some kind of non-linear transformation, for example logarithmic, when passing from the natural scene to the picture, which favors this result. In this sense, the compression performed would be close to that made by the photoreceptors of the retina, cones and rods. Graham and Field get this result when they apply logarithmic compressions to images previously filtered by Gabor (wavelets) filters and Gaussian filters (DoG, difference of gaussians) to natural scenes and pictorial works[2]. This kind of compression leads to values of kurtosis and skewness of the lightness distribution in natural scenes to comparable values than those obtained for masterpieces. These phenomena reveal the effort of the painters and they can reproduce a successful representation of the human perception in their paintings.

Other parameters have been studied, such as sparseness, evaluated by different methods, especially based on the calculation of kurtosis. In general, it is found that natural scenes present greater sparseness than works of art[2], and this parameter may be useful in stylometry . Hughes et al.[9] have used efficient sparse coding techniques for the authentication of Bruegel the Elder's works, with performance being superior to that obtained with other methods involving the use of wavelets and curvelets.

In general terms it is found that high order statistical techniques have great potential for establishing stylistic distinctions in paintings[10]. Nevertheless, as suggested by Wallraven et al.[11], computational techniques for classifying paintings by style should be improved to be considered good stylistic or aesthetic potential classifiers.

More recently, Khan et al.[12] have constructed an important image database of paintings classified by styles and painters, and tried to establish a computational method of classification based on different statistical parameters. Their results show a performance success of 50% in the classification by styles and over 60% in the classification of paintings according to authors.

Regarding color distributions in paintings, Graham and Redies[6] point out that very few works[5,11,13] have addressed the study of color in paintings and conclude there is a clear emptiness of works in this field. Pinto et al.[13] have analyzed the influence of the correlate color temperature of the illuminants (CCT) on the color gamuts of the paintings. Mureika[5], as mentioned above, has studied the fractal dimension of Pollock's paintings and established the Cielab color representation system as the best for this study. Wallraven et al.[11] have tried to establish if color is an useful parameter for classification by styles of paintings but their results are not conclusive.

Marchenko et al.[14] use the concepts of color temperature, color contrast and color palette to classify modern art versus medieval art. Nevertheless, a systematic study of the color gamuts employed by authors has not been done. Graham and Redies point out that "large-scale studies of the relationship between color statistics in art and natural scenes are still missing to date"[6].

More recently, Montagner et al.[15] have compared color gamuts of natural scenes and certain collections of paintings and obtained that when these gamuts are adjusted in the chromaticity diagram to ellipses, the results between both sets of data are quite similar, except for the orientation of the ellipses, which in the case of the paintings is a little more tilted towards the red. Nascimento et al.[16] has evaluated psychophysically the preference of observers in terms of color gamuts, which coincide with those chosen by painters.

It has been explicitly expressed by different authors that there is a lack in the extensive study of the color gamuts used in painting. Although it has been found that these cannot be used as a resource to identify a particular style within the history of painting, it is evident that each painter has used a palette (gamut) preferred of colors, according to the themes exposed, the materials and techniques used and their artistic preferences. Then, it could be considered the study of the color distributions according to each author and establish if this can be considered as a defining characteristic of his work, based on the computational analysis of his paintings.

The study behind this objective can be considered extraordinarily broad, so it is important first to narrow it down to a small number of painters. We have limited ourselves to study a number of master painter from about the same period and in which the evolution between the Renaissance and Baroque styles is observed: Titian, El Greco, Rubens, Velázquez, Rembrandt and Vermeer, and we have asked ourselves if It is possible to establish some parameters related to the color that indicate that this evolution has occurred. What we are trying to check is if within the same style or close styles the color gamut is something more personal of the author or not.

The main aim of this work is to make a statistical comparison of paintings by well-known painters, focusing fundamentally on aspects related to color: color gamuts, number of discernible colors, and other parameters of first and second order statistics, in relation to color: mean, skewness, kurtosis and Fourier spectrum. As representation systems we would use RGB, CIE1931 (x, y, Y) and Cielab (L *, a *, b *).

Method

The number of paintings analyzed varies with the author. Thus we selected 30 images of Titian (circa 1490-1576), 33 of El Greco (1541-1614), 40 of Rubens (1577-1640), 34 of Velázquez (1599-1660), 41 of Rembrandt (1606-1669) and 21 of Vermeer (1632-1675), author with smaller production. All images used are published with free access on Internet. We are not aware of the conditions in which they were captured, processed and transmitted. However, we consider that they can satisfy the demands of our work, since we do not intend to carry out the exhaustive colorimetric characterization of the same, but a global comparative study of the chromatic gamuts in the paintings of the different authors. A strict colorimetric study would imply to have hyperspectral images of the paintings in order to calculate the chromaticity coordinates pixel to pixel under different illuminants. Such a database is not currently available or does not exist. In figure 1 we show examples of the images used.

[Figure 1 near this paragraph]

We are conscious that this kind of images are obtained under uncontrolled conditions, in order to stablish some degree of error we have compared the original colors of a Macbeth chart and those obtained by RGB pictures of it with two very different cameras (CANON EOS-7D and Motorola Moto G) under D65 and D50 light sources. Figure 2 shows the results of this comparison, we can note that color performance of these kind of images is not perfect. But looking only at one device at a time, we can see that even the Mobile phone can distinguish between colors and consenquently it helps us to see trends in full paintings.

[Figure 2 near this paragraph]

From every pixel of each image we have determined its color coordinates in the CIE 1931 (x, y, Y) and Cielab (L *, a *, b *) systems. The first-order moments (i.e. mean, contrast, skewness and kurtosis) in both color representation systems and in RGB data and their logarithms (log R, log G, log B) were calculated.

In the Cielab system we have determined the number of discernible colors for each image according to the method used by Linhares et al [17]who divided the color space in cubes of the one Cielab uni t of color difference and counted the number of cubes containing pixel colors of the image. Similarly the volume of the color gamut in this color space is determined.

In the Cielab (a *, b *) chromaticity diagram we have adjusted the color gamut, according to Montagner et al.[15], to an ellipse that includes 95% of the points. From this ellipse we take the following parameters: area, orientation and semi-axis ratio. In our study we have eliminated the pixels whose RGB values are repeated less than 10 times, thus avoiding the influence of possible sources of noise in the image, discarding saturated and null values.

Results

In Table 1 we show the mean values of the color coordinates for the different sets of paintings in the CIE1931 and CIELAB systems. As we can see the values in the CIE 1931 chromaticity diagram are quite similar except for the paintings of El Greco and Vermeer. For these authors as we can see the coordinates of chromaticity (x, y) roughly coincide with those of the illuminant E. For the rest of the authors the mean values are a little more skewed towards the yellow, which could be related to the average illumination used to execute the works. In fact, it is usually assumed that the average chromaticity becomes a representation of the illuminant of the scene to be reproduced, both in paintings and in images of natural scenes. It is presumed that these authors will use for the interior lighting coming from candles which would confer a warmer tone to their paintings. In the case of Vermeer, this author used to paint scenes of interiors but with a strong external illumination of daylight through the window, which can justify its greater average neutrality. In the case of El Greco, it is more difficult to find an explanation since this author liked to use very vivid colors for the clothes of their characters or for the sky, regardless of the lighting at the time of painting.

[Table 1 near this paragraph]

These results are also observed in the CIELAB system, where it can be seen that the average b* coordinate tends to yellow (b * positive) for all authors to a greater or lesser extent, except Vermeer so that the mean chromaticity displacement is small and gives equally in the sense of a * and b * positive. In this system we can also draw conclusions about the average lightness of the paintings. As we see, there is little difference between authors, with an average lightness slightly higher than 50, except for Rembrandt, who presents a lower value, which can be understood since this author often presents a dark environment in his pictures, figure 1e.

The values for the standard deviation for most of the statistical parameters shown in the tables are relatively large. This can be expected as the variety in the paintings also for the same author is important because of the different topics and conditions involved: portraits, landscapes, interior or exterior scenes, religious or mythological themes, etcetera.

In the case of skewness and kurtosis, when the data are calculated in the system of logarithms, (log R, log G, log B) the values for all the authors are in average around 0 and 3, respectively. It was found average values between 0.01 and 0.42 for skewness and between 2.62 and 4.17 for kurtosis. Thus responding these data to approximately Gaussian distributions in line with what was found for natural scenes[18].

In Table 2 we show the average number of discernible colors according to the method of Linhares et al.[17] As we observed, there are notable differences between authors. Rubens and Titian present a greater number of discernible colors, which is not surprising after the simple observation of their paintings in which a great profusion of colors is appreciated. El Greco presents an intermediate number and clearly Velázquez, Vermeer and Rembrandt present a smaller number. It is not surprising in the case of Velázquez and Rembrandt because it is known that Velázquez used a reduced palette of colors in his paintings[1]. Rembrandt, as we have mentioned, presents many dark areas in his paintings. The result is a little more surprising in the case of Vermeer, which can be assumed a superior chromatic variety. However, most of the pictures analyzed by this author are the famous pictures of personages in the interior illuminated by the light that enters through the window. Let us say that the smallest variety of themes may be the cause of this apparent lower chromatic variety. This result has to be studied in depth by the subsequent analysis of the chromatic gamuts. It may be plausible to conclude that the older painters of this set have a greater number of discernible colors than the later ones, that is to say, those which enter fully into the more mature age of the Baroque.

[Table 2 Near this paragraph]

As it can be seen in the table, the percentage of dark pixels (i.e. pixels with values of L * <30) is greater for Rembrandt and Velázquez, showing a greater predilection for the shadows as do other Baroque painters such as Caravagio or Ribera.

As we indicated above, we have adjusted the chromatic gamuts by ellipses in the chromatic diagram (a*,b*)[15]. From these ellipses we have analyzed different parameters such as their center, orientation, area and semi-axis relation. As expected, the center of the ellipses coincides with the average values of the gamuts, already discussed above. In Table 2 we show the values of the semi-axes ratios in average values and as we observe the values obtained are between 0.41 and 0.50, although the standard deviation is high. Although the differences between authors are not very high, as we see the more rounded ellipses correspond to Rubens and are becoming a little more elongated for Rembrandt, El Greco, Titian, Vermeer and Velázquez. We cannot therefore say that a correlation can be seen with the number of discernible colors.

The orientation of the ellipses tends to be tilted towards the yellow-blue direction, which coincides with Montagner et al's results[15] for natural scenes. Nevetheless, these authors found lower values of orientation angle for the paintings they analyzed in comparison with natural scenes. That is, in the paintings selected by these authors, the orientation of the ellipses tends towards the red-green axis. In the paintings analyzed by us, the average orientations are even clearly superior to 90° for most authors, although again the standard deviations are high. These discrepancies may be a consequence of both the data sets in the two articles are different and the fact that in our case we have not done an experimental measure of the RGB values of each pixel, as Montagner et al.[15], who can obtain these values under different daylight illuminants.

As expected the results for the area of the ellipses are similar to those obtained when calculating the number of discernible colors, except in the case of Vermeer. For the set of paintings by this author, the area is larger than those obtained for Velázquez, Rembrandt and El Greco, which would show that although the number of discernible colors is smaller, the area in which the color diagram is distributed is larger, which implies a greater chromatic range. We could say that it presents fewer colors but more widely distributed. In any case, the major areas are shown by Rubens and Titian. In figure 3 we show some examples of the ellipses obtained.

[Figure 3 near this paragraph]

If we evaluate the volume of the chromatic range, considering the three color coordinates (L *, a *, b *), we find a higher value for the three older painters and smaller for the more modern painters. Again, there is an evolution in the painting of the Renaissance to the Baroque in the sense of a reduction in the global chromatic range when passing from one style to another.

In Table 3 we show the values obtained for the slopes that relate the logarithm of the power of the Fourier transform and the logarithm of the spatial frequency in space (RGB) for each one of the RGB coordinates in the horizontal, vertical and oblique directions to 45º. The values shown for the horizontal and vertical directions are always close to -2, which would be in agreement with the results obtained by other authors for paintings and natural scenes[6]. No significant differences can be seen between the different authors. The same happens with the slopes in the oblique direction, although in this case the values are greater, around -2.5.

[Table 3 near this paragraph]

Conclusions.

Several conclusions can be drawn from the analysis carried out when evaluating the different statistical parameters obtained from the digital images of the paintings. We have found characteristics common to different painters and other that establish differences. All have an average chromaticity in the first quadrant of the chromatic diagram (a * b *), with differences among painters in the average value of the coordinate b* towards yellow. This could be related to the type of lighting used at the time of the execution of the paintings, usually warm indoors. In fact the smallest displacements appear for Vermeer, who paints subjects in which the illumination is always natural, simulating the light of the day that enters the window.

Rembrandt and Velázquez present a greater number of dark pixels, i.e. shadows, which can be said to be in agreement with many of the baroque tendencies. Also the average values of lightness in their paintings are smaller, although this parameter does not seem definitive of the style, since those of Vermeer have higher values.

Although Rubens is considered as a baroque painter, we could say that it establishes a bridge between the Renaissance and the Baroque style and in fact influences Velázquez, as it is known[1]. In the same way, El Greco, although with his own style very accused, we can say that it establishes a bridge between both styles. We have found characteristics of the older painters of this group compared to the rest. Thus, the volume of the gamuts and the number of discernible colors is greater for Titian, El Greco and Rubens, compared to Velázquez, Rembrandt and Vermeer. However, the latter presents a high chromatic gamut in the chromaticity diagram, that is, when we exclude the L * coordinate.

We must also point out the common parameters to different authors or what seems to vary little. These parameters include the orientation and semi-axes ratio of the ellipses that define the gamut in the chromaticity diagram and the dependencies with the frequency of the power of the Fourier transform . These parameters values are also close to those obtained when the same study is done for natural scenes, as Montagner at al.[15] have shown, with the exception of the orientation of the ellipses that represent the gamut. Montagner et al. [15] values for the orientation for the paintings they analyzed also disagree with those we have obtained. This could be a matter of further studies in which more painters have to be included.

Both the differentiating features and the common ones are of interest in the computational analysis of works of art. Although some authors, such as Walraven et al.[11] have shown that color is not sufficient for characterization by styles, their study can be useful when comparing two painters, or sets of them, and extract the general characteristics of their paintings. According to Graham and Redies[6] the analysis of the chromatic characteristics of the paintings of the master authors has much to do and to discover, in our opinion both looking for common and differentiating characteristics between them.

Acknowledgements

The authors are grateful to the Ministerio de Industria Economia y Competitividad for their support and grant in the project DPI 2015-6471_R.

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Figures and legends

Figure 1: Examples of the images used in this work:(a) *An elderly gentleman (El Greco, 1600)* (b) B*elshazzar's feast (Rembrandt, 1635)* (c) *Peace and War (Rubens, 1629)* (d) *Danaë with Nursemaid* or *Danaë Receiving the Golden Rain (Titian, 1560).* (e) *The surrender of Breda (Velazquez, 1634)* (f) *The Astronomer (Vermeer, 1669)*

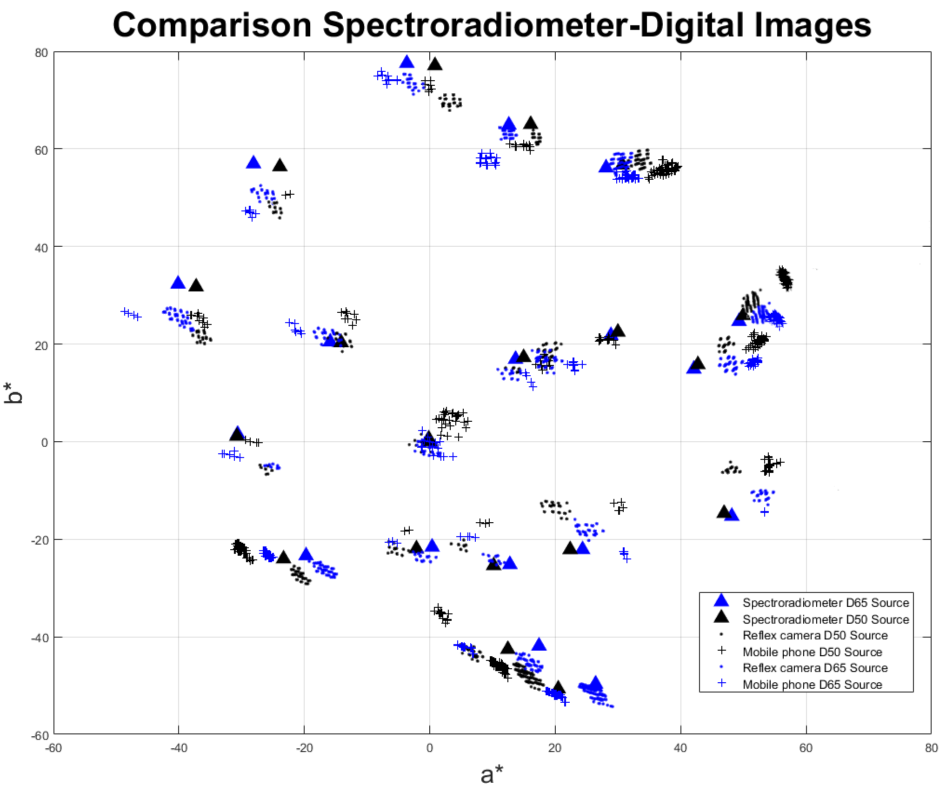

Figure 2: Comparison in *a**-*b** plane between two types of digital images of a GretagMacbeth color chart, made by a Mobile Phone (Motorola Moto G,) and a Reflex Camera (CANON EOS-7D). These images were taken under D65 and D50 light sources. Spectroradiometric colors of the chart have been also plotted as a reference.

Tables

Table 1: Mean values and standard deviation (SD) of all the images. Divided in groups of authors.

		x	*y*	*L**	*a**	*b**
Titian	Mean	0.34	0.35	51.75	0.94	8.34
	SD	0.01	0.02	7.57	2.55	4.42
El Greco	Mean	0.33	0.34	53.54	1.87	4.83
	SD	0.02	0.02	9.50	3.15	5.28
Rubens	Mean	0.35	0.35	50.45	2.85	9.31
	SD	0.02	0.02	9.76	4.39	5.13
Velázquez	Mean	0.34	0.36	51.10	0.21	9.53
	SD	0.02	0.02	8.18	3.35	5.03
Rembrandt	Mean	0.34	0.35	43.40	2.32	7.12
	SD	0.03	0.03	8.22	4.56	6.81
Vermeer	Mean	0.33	0.33	54.63	3.43	3.75
	SD	0.03	0.03	13.29	2.89	7.72

Table 2: Mean values and standard deviation obtained for each image of different parameters: Percentage dark pixels (L^*<30), number of discernible colors, color volume in CIELAB space and different parameter of the ellipses. Divided in groups of authors.

		Percentage of dark pixels	*Number of discernible colors*	*Volume*	*Semi-axis relation*	*Angle (º)*	*Area of the ellipses*
Titian	Mean	60	6304	42919	0,44	106	3455
	SD	15	2389	30656	0,45	45	2358
El Greco	Mean	52	5884	45309	0,46	98	2572
	SD	17	2720	27030	0,56	33	1434
Rembrandt	Mean	75	4028	28269	0,48	112	2387
	SD	16	1773	17260	0,5	52	2032
Rubens	Mean	56	6599	48204	0,5	90	3769
	SD	17	2646	30108	0,53	42	3002
Velázquez	Mean	63	4986	27679	0,41	95	2243
	SD	18	4160	21386	0,57	36	1602
Vermeer	Mean	55	4778	34631	0,42	98	3233
	SD	20	1502	24423	0,66	31	2031

Table 3: Slopes for each one of the RGB channels that relate the logarithm of the power of Fourier transform and logarithm of the spatial frequency for the horizontal direction, vertical direction and oblique direction (*X,Y* and 45° respectively).

		R_X	R_Y	R_{45}	G_X	G_Y	G_O	B_X	B_Y	B_O
Titian	Mean	-1.86	-1.80	-2.34	-1.83	-1.78	-2.27	-1.77	-1.72	-2.13
	SD	0.23	0.19	0.51	0.25	0.20	0.51	0.26	0.19	0.55
El Greco	Mean	-1.89	-2.00	-2.85	-1.90	-1.98	-1.9	-1.86	-1.91	-2.68
	SD	0.34	0.42	0.61	0.36	0.44	0.61	0.38	0.39	0.59
Rembrandt	Mean	-1.82	-1.83	-2.55	-1.79	-1.78	-2.41	-1.75	-1.74	-2.23
	SD	0.24	0.18	0.38	0.26	0.16	0.41	0.27	0.18	0.46
Rubens	Mean	-1.96	-1.84	-2.76	-1.93	-1.84	-2.68	-1.88	-1.81	-2.51
	SD	0.35	0.22	0.55	0.32	0.23	0.53	0.31	0.29	0.49
Velázquez	Mean	-1.88	-1.85	-2.53	-1.87	-1.83	-2.48	-1.88	-1.83	-2.37
	SD	0.25	0.22	0.43	0.26	0.22	0.41	0.28	0.24	0.39
Rembrandt	Mean	-1.82	-1.83	-2.55	-1.79	-1.78	-2.41	-1.75	-1.74	-2.23
	SD	0.24	0.18	0.38	0.26	0.16	0.41	0.27	0.18	0.46
Vermeer	Mean	-2.00	-1.83	-2.75	-1.99	-1.83	-2.69	-1.93	-1.84	-2.61
	SD	0.24	0.13	0.45	0.25	0.15	0.48	0.19	0.17	0.50

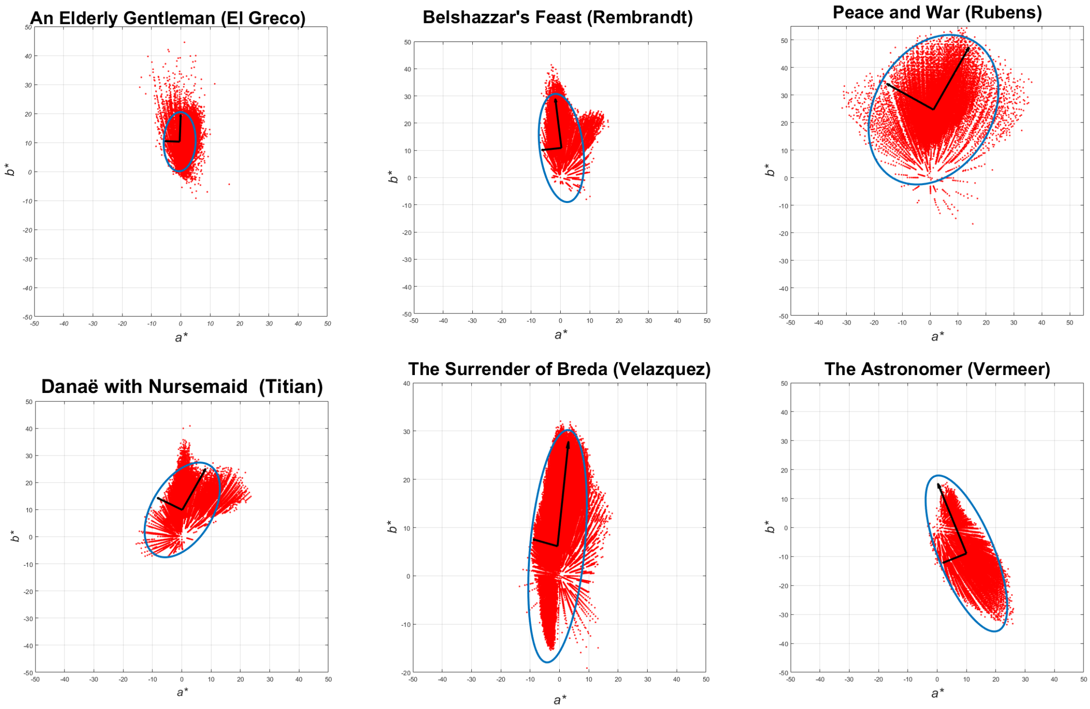

Figure 3: Ellipses of the images shown in Figure 1. These ellipses contain 95% of the pixels.