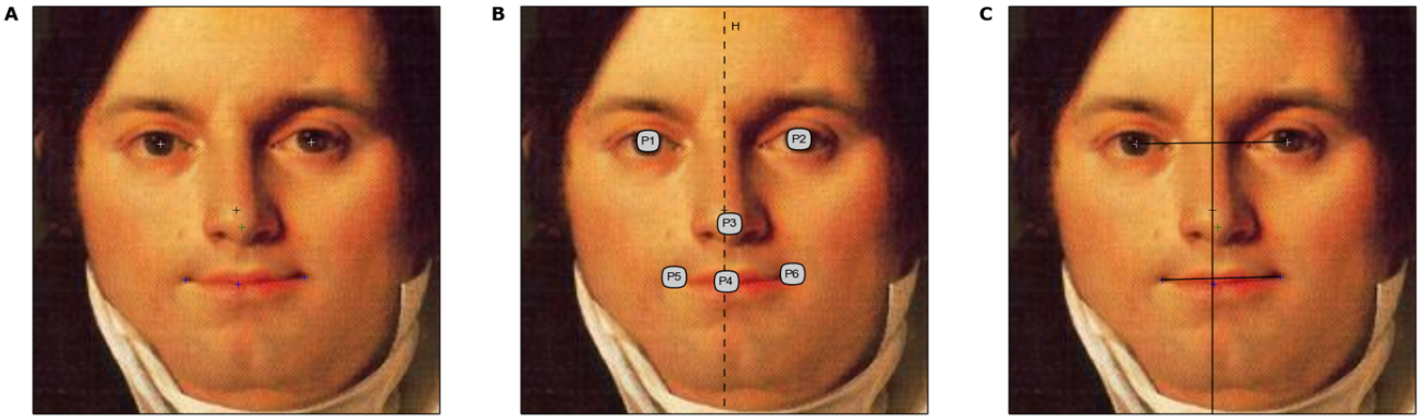


Figure 1: Steps for the calculation of the symmetry of a face.
(A) Example of face and detected points for eyes, nose, mouth and center.
(B) Vertical line, H, to divide the face into two hemi-faces, and enumerated points for all the features.
(C) Lines for calculating distances between midpoints and hemi-face line.

Peer-Reviewed

A Quantitative Approach to Beauty. Perceived Attractiveness of Human Faces in World Painting

Javier de la Rosa, Juan-Luis Suárez

Abstract: Has human beauty always been perceived in the same manner? We used a set of 120,000 paintings from different periods to analyze human faces between the 13th and the 20th centuries in order to establish whether there has been a single canon of beauty (that would maximize reproduction probabilities) or whether this has changed over time. Our study shows that when measuring averageness, symmetry, and orientation, the representation of human faces has not remained constant and that there are substantial differences between the faces depicted between the 15th and 18th centuries when compared to those of both the 13th and 20th centuries. Especially significant is the decrease in the perceived beauty of faces in 20th-century paintings, as the freedom of artists and the openness of society fostered the representation of different types of human faces other than that of classical styles.

Keywords: culturomics, digital humanities, beauty, facial recognition, computer vision

Introduction[1]

The voters who participated in the "2012 Britain's Most Beautiful Face" competition agreed on considering that Florence Colgate's face was the most beautiful one and named her the winner among 8,000 entries.[2] It turns out that the distance between her eyes and mouth is a 32% of her face, almost the exact third that Greeks considered to be the perfect proportion of a beautiful face. The results of this contest emphasized the long-standing human effort to scientifically estimate the features of beauty and to establish a method that allows for a reliable measurement of that which makes a face attractive.

The relation between the proportions of the human face and its perceived attractiveness have always captured attention and produced enormous fascination among scientists and artists alike. Even newborns seem to dedicate more time to attractive faces than to others.[3] How these proportions are meant to be the guidelines that define facial beauty has been the object of philosophic and scientific considerations since Plato's time. However, binary approaches to beauty, such as Hogarth's serpentine line,[4] the Vitruvius' "well-shaped man",[5] *divina proportione*, the golden ratio, or Fibonacci, have proven inconclusive to explain how beauty is actually perceived.[6] As it has been considered that expression of a face is the sum of a multitude of small details,[7] we can also say that the attractiveness of a face is the sum of a varied set of distinct features. The latest investigations on evolutionary psychology and neuro-aesthetics point at similar conclusions. Beauty of unknown faces seems to include elements from averageness, symmetry, sexual dimorphism, pleasant expressions, and youthfulness.[8] While the existence of universal beauty standards should be explained in terms of an adaptionist approach to attractiveness, these standards should vary across cultures if they are the result of esthetic judgments or culturally dependent values.[9]

The goal of setting the exact measurements that would help us establish the degree of beauty of a face suggests that these measures, and the beauty implicit in them, respond to the existence of a stereotype of physical attractiveness and that this stereotype might have remained constant throughout human history, even if it is a byproduct of the perceptual system's design and not the result of evolved psychological adaptations.[10] That is, a face that was considered beautiful during the Renaissance would have also been attractive in the Baroque, Neoclassical or Modernist periods. And the reverse would also be true: faces that are considered beautiful today such as those of Brad Pitt, Angelina Jolie, or Johnny Depp would have been among the most attractive faces in centuries past. These would be timeless beauties. But, is this really the case? Can we infer that the astonishing resemblance of Scarlett Johansson to the woman depicted in Vermeer's *Girl with a Pearl Earring* is due to the existence of a constant canon of beauty in human history?

Given the abundance of data required to carry out a study that comprises as many periods and genres of art history as possible, we decided to take the concept of beauty in a measurable and comparable way. We are aware that an objective definition of beauty might not necessarily correlate with the ideals of the artists and, therefore, the assumption that artists intend to represent beauty might be theoretically disputable. We do not make such an assumption. We try to establish to what extend the result of artists' practices converges or deviates from numerically measurable standards of beauty as understood by the scientific discourse. Because of methodological reasons, in our study, the focus is placed on the current standards of beauty as defined by scientific methodology in terms of face symmetry and averageness. These two indices seem to be related to the perception of beauty: symmetrical faces are the result of a non-problematic development after puberty, and therefore guarantee a

better offspring.[11] Averageness, on the other hand, operates by the evolutionary pressure of Darwin's theory of natural selection: subjects with features close to the mean for a population are preferred to others, as the probability of them having harmful mutations is lower.[12] Therefore, there is enough evidence to support the idea that both symmetry and averageness play a role in the perception of beauty: the more average and symmetrical, the more beautiful a face is usually ranked. A perfect combination of the external criterion –relation to the average face of a period– and the internal criterion –symmetry of features– would result in the most attractive face, turning a subjective opinion such as what face is beautiful into something measurable and objective.

Coming up with the right set of faces in order to determine levels of beauty in various historical periods, was not a straightforward path. Nowadays, it is becoming less difficult to perform studies on faces thanks to the overflow of photographs that we come across on any given day. The combination of digital technologies, ubiquity of cell phones and cameras, and widespread distribution of information through social networks make it relatively easy to get hold of large data sets of faces on which to perform beauty analysis and validation.[13] However, before the official birth of practical photography in 1839 and its subsequent popularization in the 20th century, the only historical record available of human images was that of art history. Drawings and paintings have always been prone to representations of human figures. Both in the portraiture genre and as part of more diverse compositions, human faces can be found in numerous works of art of most styles and historical periods. The question is how to use the faces represented in paintings such as *Mona Lisa* by Leonardo Da Vinci, *Self-Portrait Without Beard* by Vincent van Gogh, or *The Night Watch* by Rembrandt as the subject of the type of analysis required to isolate features, measure distances, or determine metrics of averageness in a set of faces.

Materials and Methods

Surprisingly, the most extensive source of paintings, as well as the easiest to work with, came from a private collection of digital images curated for years and made available on-line for free.[14] Every painting has at least information about title, size, author, and date. However, accurate dates are only provided for paintings in the past two centuries– before the 1800s, the dataset only has the century in which the painting was produced (although some open collections have appeared more recently).[15] For this reason, we treated all paintings equally and decided to use the century information as the basic unit of time for this study. On the other hand, the resolution of the images of the paintings was not very important since face detection algorithms usually work by scaling high resolution images down. For the algorithm we used, images bigger than 1024px of height or width were resized before being processed.[16] We used a Python script to

download the meta-data for each image, perform the requests to the face recognition API, and collect, clean and organize the results.[17] The algorithms for calculating symmetry and averageness indices were also written in Python, following the formulas detailed below.

Besides the calculation of the boundaries of a face and the position of several facial traits–such as eyes, nose, mouth, ears, or chin–, the algorithm we used also made guesses about the gender and age of the depicted faces, basing its estimations on the distribution and proportions of the traits and providing a threshold of confidence. Calculation of symmetry is commonly based on an early work of Grammer and Thornhill.[18] Their method makes use of 12 different points (one more for averageness): 2 for each eye, 2 for the nose, 2 for the mouth, 2 for the cheekbones, and the last 2 for the jaw. With these points, they create lines for each pair and calculate their midpoints. In a perfectly symmetrical face, all midpoints must lie on the same vertical line. For our study, the algorithm used is significantly more limited compared to that, with 3 points for the mouth (left, center, and right), 1 for each pupil, and 1 for the nose. We could have considered ears or chin, but the number of faces in which these attributes were found with enough

Figure 2: Average composites per century for female, both genders, and male. Each tuple of three images, starting from the rightmost side, represents the average composite of a given century for female, both genders, and male faces, respectively. These images were generated in order to calculate the values of averageness per century for each face. All-time composites are also available in SM as figure S1.

confidence (higher than 80%) is fairly insignificant (6%). Therefore, our method to calculate the symmetry of a face differs slightly from the one proposed by Grammer and Thornhill, while the main idea remains unchanged. Besides the points cited previously, the algorithm also gives us the centroid or geometric center of all detected features (Fig. 1A), which is supposed to coincide with the center of the face. From it, we can set a straight line that splits the face into two sides or hemi-faces. Figure 1B shows points 1 to 6 (P1 for left eye, P2 for right eye, P3 for nose, P4 for mouth center, P5 for left mouth corner, and P6 for right mouth corner), as well as the line H, that we assume to be the axis of face symmetry. We now trace segments: D1 between P1 and P2, and D2 between P5 and P6 (Fig. 1C). For these segments we calculate the midpoints M1 and M2. Symmetry is now obtained as the sum of the distances in pixels of M1, M2, P3 and P6 with respect to the line H. Only lateral symmetry is therefore estimated. For perfect symmetrical faces this value adds to zero; all symmetry values are normalized between 0 and 1, and we inverted the meaning to make plots clearer, where 1 means perfect symmetry, and 0 total asymmetry.

Let be ($center_x$, $center_y$) the point that defines the center of a face, and *roll* the rotation angle as returned by the algorithm, being 0° a perpendicular face with respect to the baseline of the frame of the painting. Then, we define the symmetry of face, *Sym*,[19] as follows:

$$Sym_{face} = 1 - \frac{Sym'_{face}}{max_{Sym'}} \quad (1)$$

$$Sym'_{face} = d_{H,M1} + d_{H,M2} + d_{H,P3} + d_{H,P6} \quad (2)$$

where the hemi-face line, *H*, defined as:

$$H = mx + k \quad (3)$$

$$m = tan(90 - roll) \quad (4)$$

$$k = center_y - mcenter_x \quad (5)$$

Formulas for the midpoints and the point to line distance are also described below:

$$M_{p1,p2} = \left(\frac{p1_x + p2_x}{2}, \frac{p1_y + p2_y}{2}\right) \quad (6)$$

$$d_{H,p} = \frac{|mp_x - p_y + k|}{\sqrt{(m^2+1)}} \quad (7)$$

On the other hand, the obtaining of averageness values involves a task much more demanding in terms of computer power. For each century an average face has been computer-generated for male, female and both (Fig. 2). In order to produce this averaged composite face, we first centered the faces according to the center point given by the face recognition algorithm. Faces were then resized to make them fit into a PNG canvas of 500 by 500 pixels at 300dpi of resolution, and given a height of 200 pixels; faces with height lower than 150 pixels were excluded to avoid blurred pixelation of the average face. This process was achieved by using affine and projective 2D transformations from the original painting to the desired canvas. Every face standardized by size was then converted into a 3D numerical matrix representing each of the layers of the RGB color

model. A regular statistical mean was then calculated over the set of faces of each century in order to obtain the average value for each pixel. Once the average matrix was calculated, it was converted back into a PNG image. The resulting quality and averageness of the composite relied on the number of faces used in each century for generating the averaged face. The same face recognition algorithm used in the dataset was then applied on averaged composites. This allowed us to measure the averageness of an individual face as the difference between its symmetry and the symmetry of the average face for that particular period.

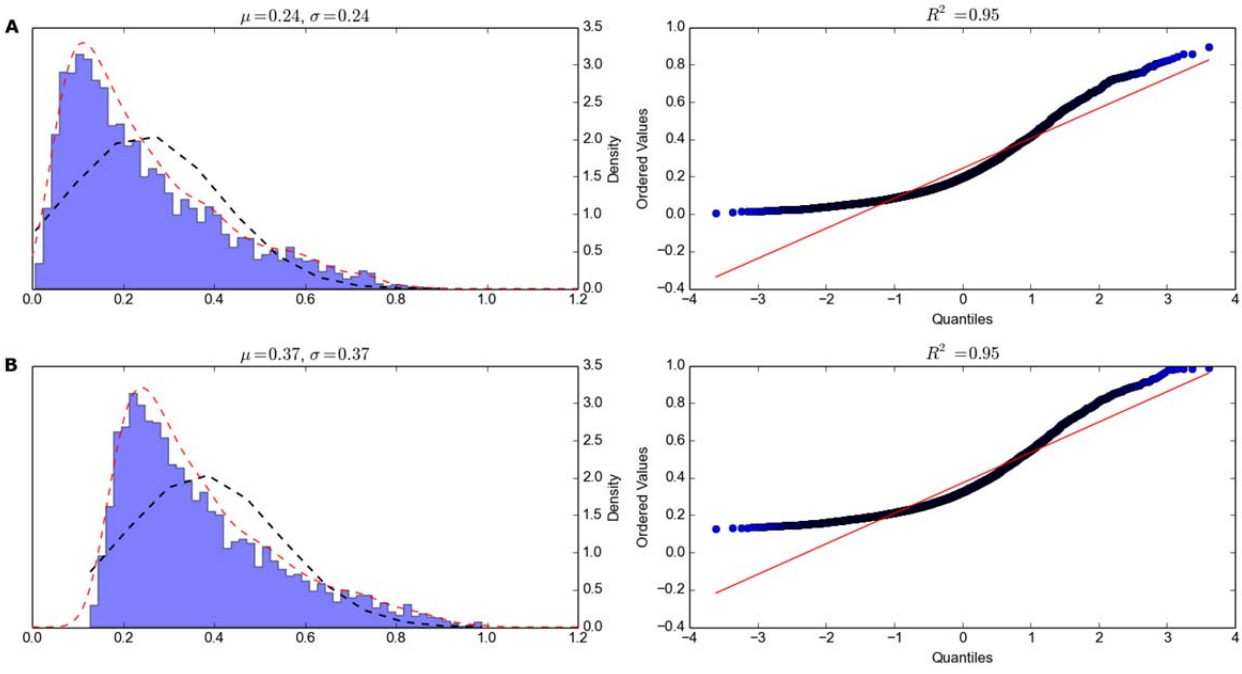
Let be F the set of k faces of a specific period of time, in our case, a century. Then we calculate the average composite as follows:

$$Avg_{face} = |Sym_{face} - Sym_{Comp}| \quad (8)$$

$$F = \{face_1, \ldots, face_k\} \quad (9)$$

$$Comp_F = \frac{1}{k}\sum_{i=0}^{k} face_i = \frac{1}{k}\sum_{i=0}^{k} \langle R_i, G_i, B_i \rangle \quad (10)$$

Figure 3: Normalized histograms (left) and Q-Q plots (right) for values of symmetry (A) and averageness (B). Gaussian density estimations are shown in dashed red lines, and probability density function estimations are shown in dashed black lines. Both distributions follow a normal distribution (p=3.31e-05 and p=3.68e-05, respectively, after running a KS test).



Averageness refers to the degree to which a given face resembles the majority of faces. In our study averageness values go from the most average, 1, to the least, 0. Figure 3, A and B, shows the histogram and the density estimation for the distributions of both symmetry and averageness values, respectively.

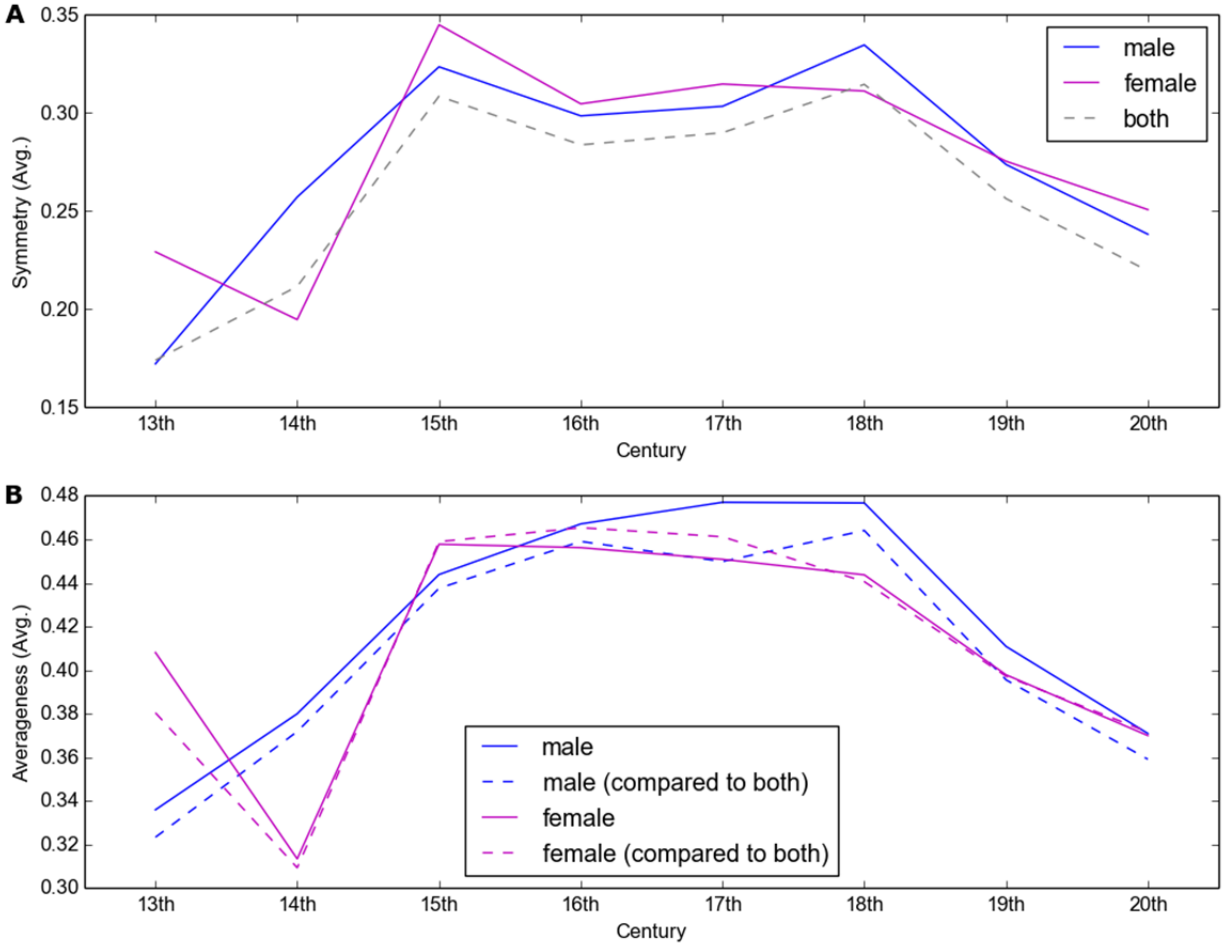
A considerable amount of paintings and faces were needed to draw valid conclusions about trends in human representation and facial attractiveness across historical periods. We retrieved and analyzed a data set with over 120,000 digital images of paintings covering styles and artistic periods spanning from the 13th to the 20th century. We applied face recognition algorithms to these images to remove all paintings that had no recognizable faces in them, to end up with 25,000 paintings and over 47,000 human faces. For the current study only 5,800 faces that fulfill the following criteria were considered: frontal faces no smaller than 150 pixels in height, with pitch and yaw angles between 20° and -20° with respect to the vertical line, and with valid information for at least the following traits: eyes, nose, mouth, height, width, and center of the face. Face rotation or roll was fixed geometrically. Once we had identified the traits of the detected faces, and based on meta-analysis of symmetry and averageness,[20] we were able to compare the beauty and attractiveness of faces in order to determine different trends and variations across time periods as they appeared in the history of painting.

A decline in perceived beauty

Average values of symmetry per century are shown in figure 4A for male, female, and both genders combined. It can be noted that most symmetrical female faces were found in the 15th century, while most symmetrical male faces occurred in the 18th century. After that, both genders rapidly became much more asymmetrically represented in all styles during the 19th and 20th centuries. From the 15th to the 18th century, representations of human faces seem to have moved within a stripe of relatively constant symmetry with maximums of symmetry around 0.35 and minimums of 0.32. This stripe of constant symmetry conforms to what we call the classical representation of the human face, which is the product of two factors: first, a cultural conception that placed the highest aesthetic valuation on previous models of beauty, specifically in the Greek and Roman models recovered during the Renaissance, and made their imitation and reproduction the goals of the artist; second, a training system based on workshops and academies that fostered an education around skills and models that helped achieve the former goals.[21] Variation within the classical mode can be attributed to the action-reaction effects that certain schools provoked against the previous dominant style, such as the separation from the ideal of symmetry proposed by Rococo artists versus more traditional styles such as Baroque and Neoclassicism.[22]

The appearance of disruptive styles in painting starting in the 19th century, a trend that became more acute throughout the 20th century when movements such as Modernism, Avant-Garde, Impressionism, Surrealism, Cubism, and Pop-Art dominated the art scene, came with a radical distancing from the ideal of symmetry in the representation of the human face. Paintings like Picasso's *Les Demoiselles d'Avignon*, Duchamp's *Nude Descending a Staircase, No. 2*, or Pollock's *Male and Female* responded to the new paradigms of human representation and to new approaches to beauty (Fig. 5).[23] This ultimately led to a poor detection of

Figure 4: Peak values of symmetry and averageness are found in the 15th and 18th centuries, decreasing slightly in between, but notably cresting in the extremes of the period (values of 1 indicate perfect symmetry, while 0 means total asymmetry). After the 18th century both values decrease equally until the 20th century, where we encounter the lowest average of symmetry and averageness of the last five centuries. Corresponding figures for specific painting styles for each century can be found in tables S1 to S5. (A) Average values of symmetry for the period between the 13th and 20th centuries, represented for male, female and both genders combined. (B) Average values of averageness for the same period for male and female compared to the corresponding composite and the composite of both genders.

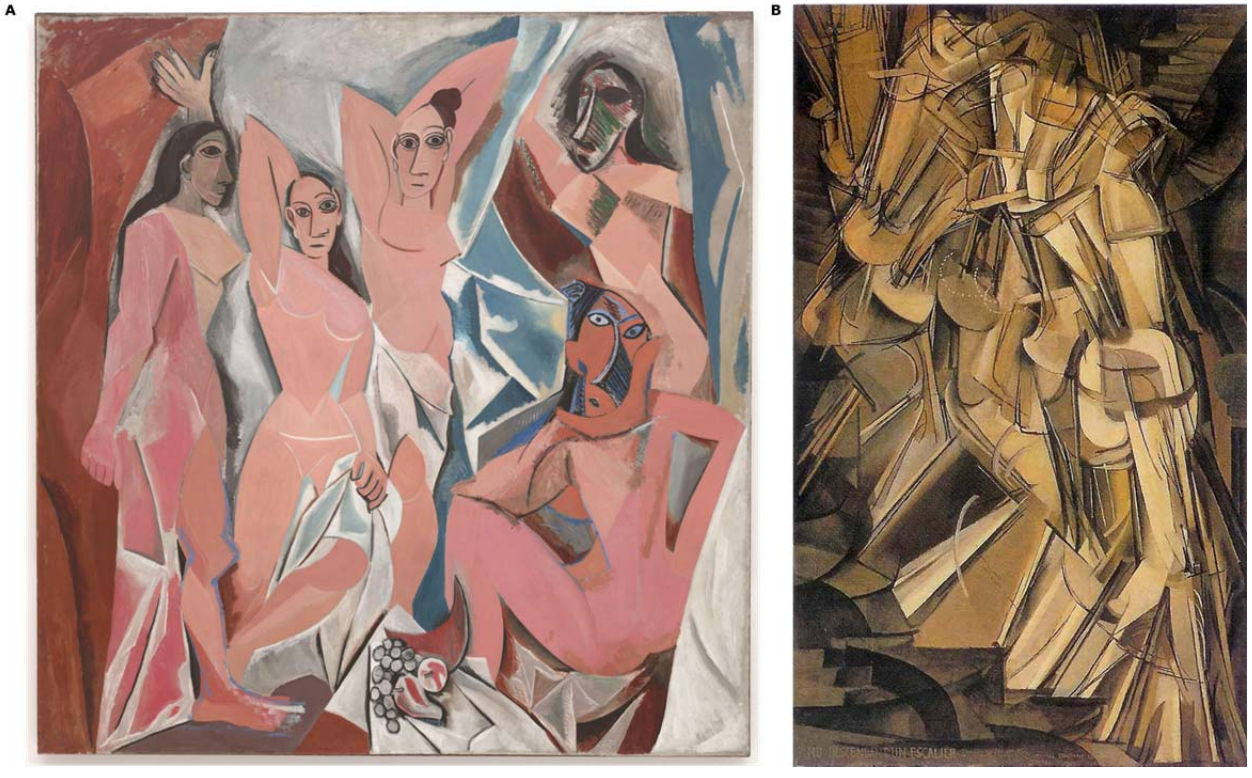


such faces by the algorithm, and therefore it explains why the averaged faces for the 20th century are still close to the picture-perfect representation of a human face (Fig. 2).

In the 20th century we also observe a considerable decrease (Fig. 6) in the ratio of faces detected in paintings as most of the aforementioned styles did not render realistic models of the human, rejected beauty, or simply tended to focus on concepts, dreams, or ideas in which the human being was not the central object.[24] This trend coincided with both the irruption of photography as the favorite medium to represent the human face and the movement of nonrepresentational art observed at the beginning of the same century and characterized as the "dehumanization of art."[25]

A consequence of these differences in symmetry is reflected in the oscillations in averageness throughout art history. Figure 4B showed the distribution of

Figure 5: New representations of the human face arose in the past century.
(A) Les Demoiselles d'Avignon by Pablo Picasso, 1907 (oil over canvas, 96 in × 92 in). Museum of Modern Art, New York. Image in the public domain ("Les Demoiselles d'Avignon," MOMA, accessed January 1, 2015, http://www.moma.org/explore/conservation/demoiselles/)
(B) Nu descendant un escalier n° 2 by Marcel Duchamp, 1912 (oil over canvas, 577⁄8 in × 351⁄8 in). Philadelphia Museum of Art, Philadelphia. Image in the public domain ("Nude Descending a Staircase (No. 2)," Philadelphia Museum of Art, accessed January 1, 2015, http://www.philamuseum.org/collections/permanent/51449.html)



averageness for male and female faces compared to their gender-specific averaged composite. In dashed lines we can also see the same distribution but with regards to the average face generated from both genders. A two-sample Kolmogorov–Smirnov test allows us to see that there is no significant difference between the two male distributions ($p=0.92$) and the two female ones ($p=0.51$).

Averageness, the difference between a face and the averaged composite face of each century, can shed light on how similar faces are to each other. For male faces, we observe that the levels of averageness are low in the 13th century, but then begin to increase until the 17th century, when averageness of faces gradually decreases until the minimums recorded in 20th-century painting styles.

Culturomics of art history

Exact measurements such as averageness and symmetry help us better understand the various ways in which human faces have been depicted throughout the history of painting. However, as attested by art historians through traditional scholarship, these representations have not always remained constant, as different artistic styles have attempted their own ways of capturing facial beauty. After our analysis, we can conclude that there have been variations in the form in which facial beauty has been represented over time, and that these variations can be measured and tracked accurately. Of course, as in all data-based research endeavors, the better the dataset, the better the conclusions we can infer from our analysis. While there is a clear stripe conforming to features of classical representation of the human face from the 15th to the 18th centuries, both the 13th century –Gothic style– and contemporary art have shown clear deviations from the classical paradigm. Especially interesting is the data from 20th-century artistic styles, which shows low levels of both symmetry and averageness as well as a reduced proportion of total faces captured when compared with previous centuries.

These results conform to the views of art historians regarding the aesthetic and methodological disruptions that occurred after the vanguards. There has arguably been a change in the concept of art itself as well as in the theories that explain and criticize it. It is nowadays accepted that the representation of the human does not necessarily attempt to represent beauty. This shift in thought is clear in the data analysis and opens the door to a second phase of the investigation. By contrasting the aesthetic theories of specific periods and artists against the data, we would be able to establish their levels of conformity to and deviation from the objective measures of beauty. This would allow us to complement the qualitative and conceptual analysis of art history with the study of quantitative data. Combining these two levels appropriately should be one of the methodological aims of any culturomics science.

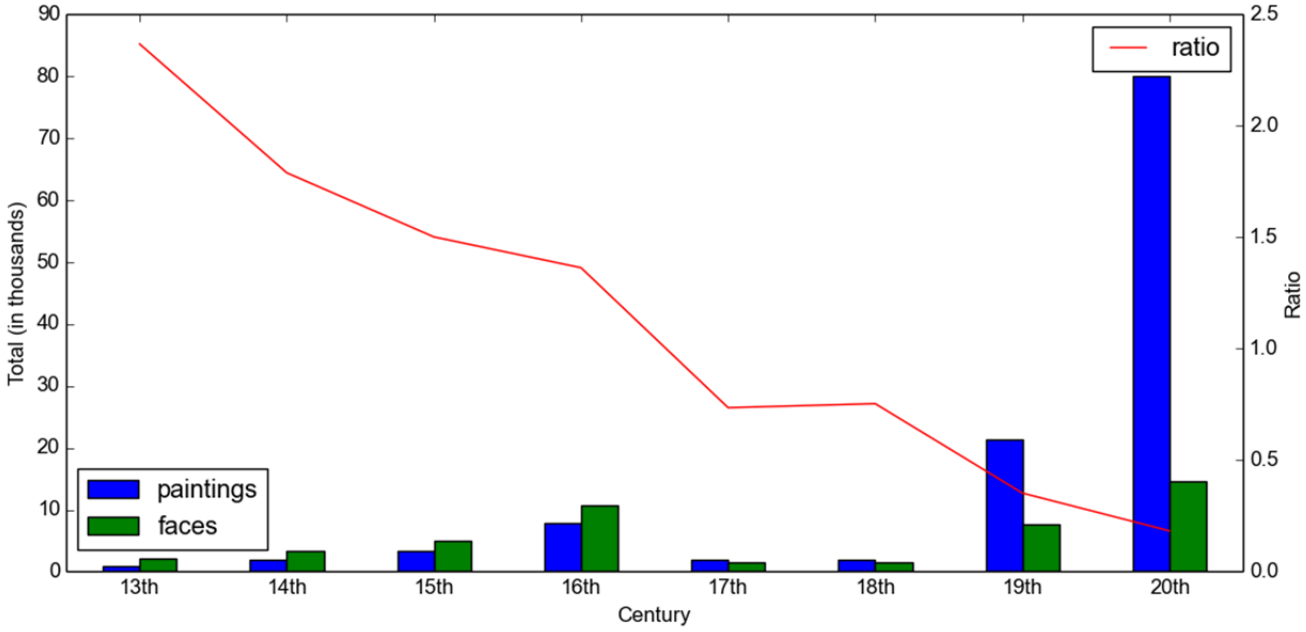
The separation from the classical mode of representing the human in con-

temporary art also serves as a reminder of the bias that we imposed on the analysis of perceived beauty by employing such accurate measuring systems. This bias also shows the interesting close relationship between classic ideas of beauty and art in Western cultures, and mathematical notions that support data-driven methods of research. While it is evident that the examples in Picasso's, Duchamp's, and Pollock's works show deviations from painting styles which depict faces that conform better to measures of symmetry and averageness, the judgment of whether these human faces are more or less beautiful than previous cases remains as aesthetic one. The contingency of aesthetic values is subject to fads, trends, reactions, and public opinion.[26]

Better algorithms can help us be more precise in the measurement of objective elements, although it has to be noted that the discipline that studies how social movements get started, become important and disappear, remains in its infancy.[27] Once we have improved the way to measure and analyze both the internal features of art works and the dynamics of social movements that create judgments about those works, we will be able to approach these types of problems in a more accurate manner.

Another relevant factor to take into account has to do with how representative the sampling used for this study is. While we are certain about the validity of the used set as related to art history, it is impossible to ascertain how representative these faces are of the real populations living in the various historical periods. However, we have observed that there is a correlation between the production of various types of media and the size of the human population in various

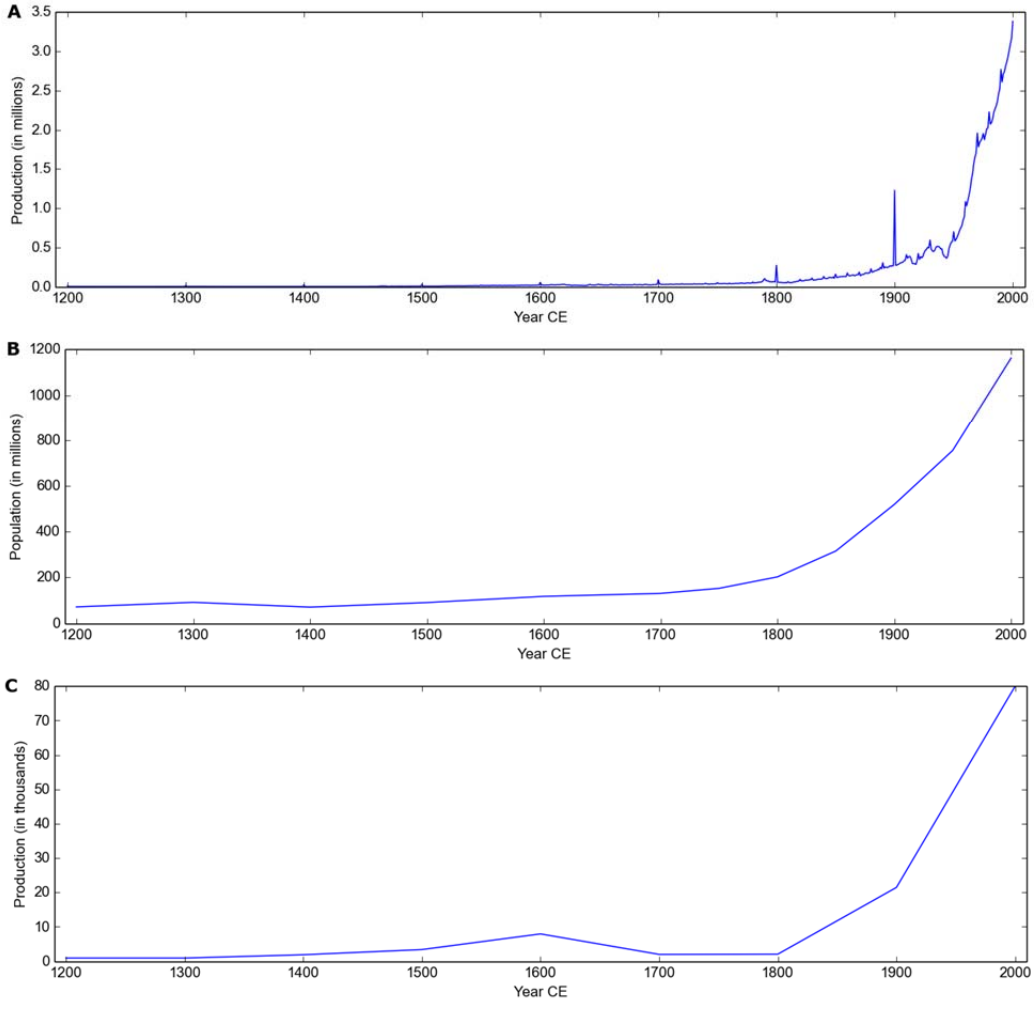
Figure 6: Number of paintings and faces per century, and ratio (faces per painting) between both.



countries throughout time (Fig. 7, A and B). The more people, the more media is produced (p=1.02e-05 for books). This correlation remains true for paintings (p=3.92e-04, see figure 7C).

Although not explicitly discussed in this work, we have also verified that age, gender and face orientation, along with symmetry and averageness in the representation of human faces in paintings can become a complementary and objective way to identify and characterize styles and movements. Along with the exhaustive tagging for techniques, materials and the analysis and recording of chemical products used in art production, this could become the basis for the culturomics of art history.[28] Nevertheless, and although this does not contradict our findings, it is clear that there is also a variety of complex social, aesthetic and evolutionary elements that influence our judgment on beauty. Capturing these constructs into proper algorithms has not resulted yet in perfect solutions to ac-

Figure 7: Population growth and media production over time. (A) Book production as contained in WorldCat since year 1200. (B) Population growth of Europe, where most paintings are from, in the same period. (C) Paintings in our dataset.



count for changes in perceived beauty. As we have previously stated, this has to do in part with the close relation between classic ideas and mathematical models that biased the analysis towards certain ideas of beauty. It is also important to note that many of these variations are due to the pressure that culture exerts in the short term on the adoption of different traits, and the deviations that this provokes from well-established, long term genetic features related to beauty, reproduction, and social acceptance and belonging.[29] Thus, it is important that any approach to the culturomics of art history and beauty also takes into account cultural evolution and cultural history as forces that shape the results we find in the data, and that have to contribute to the explanation of those results.

Supplementary Material

To this article supplementary material can be found at HeiDATA Dataverse Network http://dx.doi.org/10.11588/data/10057

Figures S1-5
Tables S1-5
External Database S1. List of paintings and metadata, paintings.xlsx
External Database S2. List of faces and features, faces.xlsx
External Database S3. List of authors and number of paintings, authors.xlsx

Notes

[1] Acknowledgments: We acknowledge the support of the Social Sciences and Humanities Research Council of Canada through a Major Collaborative Research Initiative. And the Canada Foundation for Innovation through the Leaders Opportunity Fund.

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[16] Summary tables of the dataset are shown in tables S1 to S4 and figures S2 to S5 in the section Supplementary Materials (SM).

[17] We used the service faces.com before it was purchased and shut down by Facebook in 2012. "Facebook to buy facial-recognition startup: sources" *Reuter*, accessed January 1, 2015, http://uk.reuters.com/article/2012/06/18/us-facebook-face-idUKBRE85H1A320120618.

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