Computational Aesthetics in Graphics, Visualization, and Imaging
Angus Forbes and Lyn Bartram (Editors)

EXPRESSIVE 2016

Parameterized Skin for Rendering Flushing Due to Exertion

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Abstract

It is known that physical exercise increases bloodflow and flushing of the facial skin. When digital artists hand-paint the textures for animation of realistic effects such as flushing due to exertion, they observe real-life references and use their creativity. This process is empirical and time-consuming, with artists often using the same textures across all facial expressions. The problem is that there is a lack of guidelines on how skin color changes due to exertion, that is only surpassed when scans of facial appearance are used. However facial appearance scans are best suited when creating digital doubles and do not easily fit different characters.

*Here, we present a novel delta-parameterized method that guides artists in painting the textures for animation of flushing due to physical exertion. To design the proposed method we have analyzed skin color differences in L*a*b* color space, from 34 human subjects' portraits before and after physical exercise. We explain the experiment setup configuration, statistical analysis and the resulting delta color differences from which we derived our method parameters. We illustrate how our method suits any skin type and character style. The proposed method was reviewed by texture artists, who find it useful and that it may help render more realistic flushed exertion expressions, compared to state of the art, guesswork techniques.*

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.7]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture.

1. Introduction

Rendering skin is an aesthetic experiment, assisted by scientific knowledge, because the entertainment industry seeks to render believable characters, with engaging appearance and expressions. Traditionally, artists paint by hand all the required facial expressions' textures (eg.: diffuse color, melanin or hemoglobin maps) to render skin's flushing from physical exercise. To render skin appearance, artists study references such as medical images of skin's anatomy, which is a highly experimental iteration process combined with guesswork, thus becoming time consuming and expensive. The problem is the lack of guidelines on how skin color changes to assist artists animate flushing following physical exercise.

For rendering human-like characters often facial scans of actors are made, capturing even the finest details of the skin, such as pores or the dynamic blood flow, along with the animation. The drawback of this solution is that is expensive to freelance artists and to many production studios. Furthermore facial scans of human skin and expressions are not designed to generate transferable models that can easily suit different characters.

Often, as a result, the blood flow variation that models the skin color is generally ignored in many 3D characters; i.e. facial expressions of exertion are commonly animated without flushing. Digital Domain considers dynamic bloodflow the key for achieving accurate skin color when animating expressions. As Kelly Port (visual effects supervisor for Digital Domain) said *"dynamic skin color changes gave the pixies faces an additional level of realism"*, to explain the technique to render the pixies' skin for Maleficent movie (2014, Roth Films and Walt Disney Pictures) [Wir14]. In this paper, we present a delta parameterized texture painting method to guide artists in rendering skin flushing due to physical exercise. In order to analyze and validate human skin color variation, we conducted an experiment that collected a database of 64 human subjects portraits, taken before and after physical exertion. The digital photos were shoot under controlled, diffuse illumination and color calibrated (see figure 2). The RGB images were converted to L*a*b* color space to calculate color differences using the CIEDE2000 formula [SWD05], whose results correlate better with human visual perception. Color samples were collected from the forehead, nose, superior and inferior lip, chin, left and right neck plus left and right cheek for physical exertion and were compared to the neutral expression for each participant. A One-Way Repeated Measures ANOVA statistical analysis of all data determined most significant color changes according to L* (lightness), a* (red to green axis) and b* (yellow to blue axis) separately, in order to better charac-

DOI: 10.2312/exp.20161061

terize skin color variations. We designed our method using the L* (lightness) values, as well the a* values, because they correlate almost linearly with melanin and hemoglobin, respectively [Tak98]. We performed a user study among digital artists in order to evaluate the proposed method application and compare it to current, empirical methods. Our parameterized method it is flexible because it is independent of the art style and fits any character type. We illustrate it with examples using a human-like character, a cartoon, and a fantasy creature. The main contributions of this paper are: 1) a database of 64 human subjects photos for artists to use as references and for other researchers to carry further analysis that can open new lines of research for skin shading. 2) a skin color analysis of flushing due to exertion, segmented into ΔE_{00} plus L* (lightness), a* (red-green axis) and b (yellow-blue axis); 3) a derived method presented as an illustrated tutorial to assist artists paint flushed skin textures due to exertion.

2. Skins' Anatomy and Light Interaction

Skin is a translucent medium whose color is determined by its main chromophores concentration and distribution, and their interaction with light: melanin in the epidermis and hemoglobin in the dermis. We focus our method on hemoglobin variation, comonly referred as flushing, because it happens fast enough to be rendered in real time. Shields et al. [SMS90], measured blushing duration and states that it typically occurs within 2 seconds after the stimulus, having a median duration of 20 seconds, and could last up to 15 minutes. The outermost layer of the skin is the stratum corneum, mainly composed of dead cells (keratin-filled corneocytes) embedded in lipids. The stratum corneum reflects about 6% of incident light, irrespective of wavelength, without coloring it; please refer to figure 1 describing the pathways of light throught the skin layers. Photons that penetrate the stratum corneum will suffer a large number of scattering events before they come out of the skin (e.g.: light can take close to 360 scattering events inside the skin before it exits).

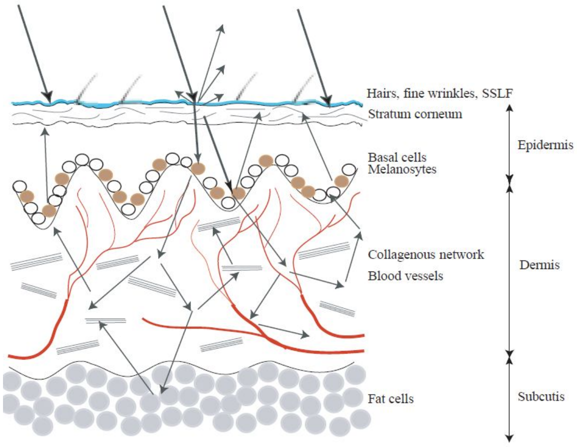


Figure 1: *The structure of the skin layers with corresponding light interaction. Only approximately 6% of incident light is reflected at the stratum corneum; most of the light penetrates the skin, interacts with its components and leaves at a nearby point of entry. Image adopted from [INN07].*

The next layer is the epidermis, which contains three main types of chromophores: eumelanin (deep brown), phaeomelanin (yellow to reddish brown) and carotenoids (yelow). The ratio between eumelanin and phaeomelanin varies according to each individuals' skin phototypes, ranging from very light complexioned Caucasian skin (type I) to black African skin (type VI) [You97]. When light enters the epidermis it is absorbed and scattered by the epidermal melanin pigment [Kol06]. Light then travels to the dermis where is absorbed by hemoglobin and is scattered back by collagen fibers. The dermis, located beneath the epidermis, is structured by collagen and elastin and is irrigated by blood vessels. The varying reddish tint of the skin is due to hemoglobin in dermis, being more easily seen in areas where the stratum corneum is very thin or absent (eg.: the lips or mucosae) and in albinos, which lack (or have a reduced amount of) melanin. So, light that interacted with human skin has travelled twice through its layers and carries two types of information, which determine skin color: the specular reflection of the stratum corneum (that should be of the same color of the illuminant) plus the subsurface scattering effect (determined by the melanin and hemoglobin chromophores concentration and distribution). Skin appearance and reflectance also change temporally with physical exercise or sweating (among other factors).

2.1. Related Work

In this section we review computer graphics models that seek to render blushing effects. Hanrahan and Krueger [HK93] rendered flushing faces with hemoglobin variation parameters controlled by a dermis texture map. Their model can render flushed, burnt and relaxed expressions. Kalra and Thalmann [KT94] presented a model for rendering emotions with color variation. They divide the expression pattern duration in four stages: attack, decay, sustain and release. From a Bezier path (vector-based curves), the user can define the shape and mask shading for the color variation representation of a specific area. Patel presented the FACES software [Pat95] that animates facial movements and changes facial coloration for specific areas of the face. The FACES system is self-contained and is not integrated with current skin shading pipelines. Borshukov et al. [BL03] captured skin appearance and performance from human actors and stored the data as animated diffuse maps. Their real-time technique, *Playable Universal Capture*, was used in *The Matrix* film and was implemented for video games by using principal component analysis to compress the large motion capture data sets. Yamada and Watanabe [YW04, YW05, YW07] measured skin facial color changes for expressions of fear, anger and laughter on the forehead and cheeks, using facial skin temperature and color information. The authors synthesized enhanced facial color images by increasing hue and saturation values, using arbitraty multipliers. Melo and Gratch presented a model for simulation of blushing associated to shame and pride, that is manipulated by user-defined mesh masks [MG09]. The authors do not provide parameters to render blushing, it is controlled by the user's creativity. Jung et al. proposed a comparative table of each expression with a high level description of its skin color change, based on physiological knowledge and on Plutchik psycho-evolutionary theory, [JWKF09]. Jimenez et al. [JSB*10] present a chromophore transfer model for real-time rendering of skin color changes, supported by in vivo capture of melanin and hemoglobin maps. They render hemoglobin variation for the six universal facial emotions of anger, disgust, fear, happiness, sadness and surprise, according to P. Ekman [Ekm73], plus the effects of physical exhaustion and alcohol consumption. However the model present by Jimenez et al. requires expensive chromophore capture equipment. The *Facial Color Transition Model* models skin color changes after comparing and analyzing 60 animations. The model is based on the human personality theory, which results in non-realistic clor changes (e.g.: green to express acceptance), making it best suited to animate non-realistic characters [PSCK11]. A dynamic texture process derives skin color changes from a library of facial expressions, which are tranferred from one character to another, that can be customized to fit facial locations and color intensity [LC12]. Flushing is controlled at the free will of the user, as parameters for its configuration are not provided. The folowing paper measured specifically human skin color changes before and after physical exercise in RGB color space [SKA*12]. Visually inspecting the model final renders, they depict reliable skin reflectance (apparently from sweating) but with decreased skin color flushing.

Despite the contributions of the above discussed models, they do not provide artists with general parameters that can assist them in rendering skin flushing, specifically due to physical exertion.

3. Experiment Protocol

In order to measure skin color variation we conducted an experiment for which we photographed 34 participants' faces, before and after physical exercise. Participants were aged between 18 to 62 years old, male and female. In the next section we explain all the experiment setup and technical details.

3.1. Experiment Setup

The experiment design was submited to the local Ethics Committee for approval. In order to minimize health risks we screened the physical condition of the candidates using the Canadian Physical Activity Readiness Questionnaire (PAR-Q) [TRS92]. All selected candidates were explained the experiment and signed an informed consent. Participants were asked to jump rope during 3 minutes (1min + 1 min + 1 min) to make them blush; in case the participant does not blush after one session of 3 minutes of rope jumping he would be asked to repeat this session a second time up to a maximum of 3 times. The camera was placed on a tripod from aproximately 1 meter of the participant, and it was configured to capture in raw format, with similar capture settings across all experiment: 35mm focal lenght; exposure at 1/60 sec, aperture 4,5 and 800 ISO. The flash of the camera was turned off and the participants' faces were lit with a three-point uniform lighting set up (without hard shadows or highlights), using a quartz-halogen 3200°K light lamps. One lamp was placed against a white fabric in the background to illuminate the background and create rim lighting. The other two lamps were covered with a softbox and placed in a 45° angle from the participant, to cancel shadows from each other. Prior to exercising the participant was photographed in frontal pose holding an X-Rite color checker passport for white balancing the camera and color calibration of the images, please see example in image 2.

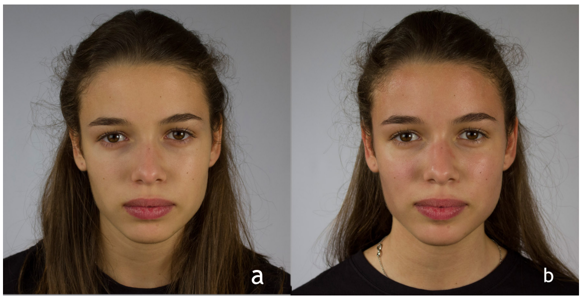


Figure 2: *Participant photographed before (a) and after physical exercise (b), where the facial flushing can be observed by naked eye.*

Images were color calibrated in Adobe Camera Raw, cropped and converted to L*a*b* color space. Skin color samples were collected in Adobe Photoshop, using the color picker tool that averages the pixels of each area into one L*a*b* value. Samples were collected from the forehead, nose, superior and inferior lips, chin, left and right cheeks and left and right neck. Facial segmentation into these areas followed the skin specular distribution as exemplified by [GHP*08]. Small color samples, picked by hand, allow to avoid noise like shadows or highlights plus skin features like pimples, beard or freckles. All the color samples of after physical exercise were compared back to neutral for the corresponding facial location.

3.2. Images Analysis in L*a*b* Color Space

Working in L*a*b* color space allows to characterize separately each axis color. L* describes Lightness and varies from 0 (black) to 100 (white); the a* axis ranges from -60 (green) to 60 (red) and the b* axis ranges from -60 (blue) to 60 (yellow), see figure 3. L* values are related with melanin concentration, low L values mean higher melanin concentration; a* values are correlated with hemoglobin variation, higher a* values mean increased saturation. b* values for representing skin will very likely be found on the yellow part of the axis, where higher values mean vivid colors.

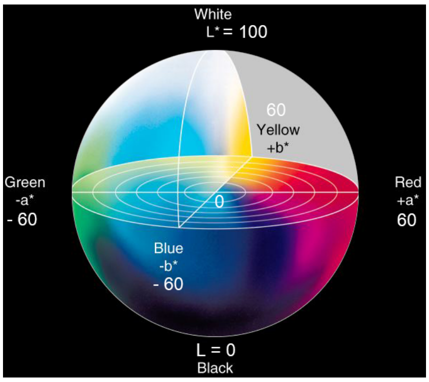


Figure 3: *L*a*b* color space figure, where the center is achromatic and color saturation is higher at the extremities.*

L*a*b* color samples were inserted into a spreasheet provided by [SWD05] for color difference calculations in the CIELAB2000 formula. The human threshold for the perceptibility of color differences in the CIELAB2000 formula starts at 1,5 delta [ALP*06]. Table 1 represents Delta E range values related to visual perception.

Delta E values	Visual Perception Meaning
0-1	A normally invisible difference.
1-2	Very small difference, only obvious to a trained eye.
2-3.5	Medium difference, also obvious to an untrained eye.
3.5-5	An obvious difference.
>6	A very obvious difference.

Table 1: *Delta E values related to visual perception.*

3.3. Results

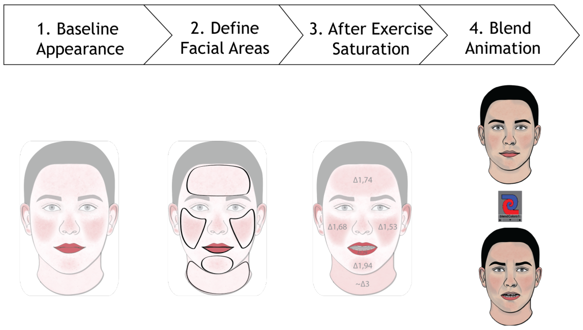
Calculated color differences for the 34 participants show that most ΔE_{00} color changes happen in the neck, followed by the cheeks, the chin, forehead, inferior lip, nose and the superior lip, please refer to table 2. To understand exactly what these color changes mean we have to observe each L*a*b* axis separately. Lightness color changes are most visible on the superior lip (Δ1.59) and right neck (Δ1.56); which mean a *very small* increase of brightness. The remainder locations depict invisible (<1.5) color changes. Color changes in the a* axis are most visible in the neck, depicting *medium color changes*, which is related with increased reds, related to flushing. *Very small color differences* in the a* axis are observed in the chin (Δ1.94), inferior lip (Δ1.79), forehead (Δ1.74), right cheek (Δ1.68) and left cheek (Δ1.53). The superior lip and nose have invisible color changes for the a* axis. Color differences for the b* axis are all inferior to <1.5, thus invisible.

	ΔE_{00}	St. Dev.	ΔL	St. Dev.	Δa	St. Dev.	Δb	St. Dev.
Right Neck	5,17	2,71	1,56	5,36	3	1,95	0,26	1,4
Left Neck	4,77	2,88	0,38	5,35	2,59	1,92	0,41	1,21
Right Cheek	4,61	2,55	1,24	4,89	1,68	2,56	-1,21	1,25
Left Cheek	4,25	2,64	-0,59	5,03	1,53	2,3	-0,97	1,57
Chin	4,14	2,51	1,33	4,44	1,94	2,55	-0,15	1,28
Forehead	3,39	2,02	0,09	3,75	1,74	2,15	-0,59	1,37
Inferior Lip	3,31	2,46	0,59	4,11	1,79	2,75	0,74	1,11
Nose	3,28	2,81	0,18	4,23	1,06	1,72	0,62	2,03
Superior Lip	2,84	1,88	1,59	3,24	1,09	2,86	0,5	1,31

Table 2: *After physical exercise deltas with corresponding standard deviation values according to facial locations for the 34 participants.*

4. Skin Painting Method

We created an illustrated tutorial (abreviated in figure 4) to assist artists in the process of painting flushed skin due to exertion by following the provided delta values. We used the a* axis (red to green) color differences that are related to flushing for painting the hemoglobin texture. The input texture for our method (step 1) is the standard hemoglobin (or subdermal) texture that the digital artist paints to render the baseline appearance of the character. This texture is painted usually with the lips vermillion as the most blood saturated area of all face. For the second step the artist should define the boundary of the flushing areas, such as: forehead, inferior lip, chin, neck and cheeks. The skin color changes are subtle for human-like characters. For the third step it is recommended to hand-paint (e.g.: by desaturation) the areas from the most flushed (the neck) to the least (the cheeks), following the delta step increments. However, if the artist is animating a cartoon, with more extreme expressions and poses, it can stretch these color differences, as long as the hierarchy of these is respected. Consequently this hierarchy concept means that the neck should always be the most flushed facial location comparatively to all other facial areas, which is followed by the chin, the inferior lip, forehead and cheeks. The fourth step illustrates a human character with a neutral pose (on top, and below it) an after physical exercise expression, as examples of two keyframes that can be interpolated for animation.



Paint the baseline, neutral hemoglobin texture, according to your character unique features. Usually the lips vermillion is the most flushed area.

Define facial areas boundaries for the saturation increments: forehead, inferior lip vermillion, chin, neck and cheeks.

Saturate areas following our method deltas. Right and left neck depict medium color changes. The chin, inferior lip, forehead and cheeks depict small color differences compared to neutral hemoglobin texture.

Now the artist can animate the texture blending between neutral and after physical exercise expression.

Figure 4: *Skin painting method for animation of flushing due to physical exercise. Method illustrated for a human-like character.*

4.1. Results

We present our skin painting method with final results illustrated for a human character, a cartoon and a creature. The digital artist can use any painting style. It can be seen that for the 3 characters, the neck is the most flushed region, followed by the chin, inferior lip, forehead and cheeks, please refer to image 5. Human visual perception has difficulty in distinguishing skin color changes for highly saturated values like in the lips.

Despite more extensive validation, we have asked two professional texture artists from the videogame industry (Ready at Dawn Studios) feedback on if the proposed method can reduce skin texture painting time and if it can provide more accurate results, compared to traditional techniques. The feedback is generally positive for achieving realistic end results, but regarding the speed it needs further testing. We summarize the feedback of Brandi Parish: *"As of now it is hard to gauge if it'd help actually speed up texturing a head, but I think it would help achieve a more realistic end*

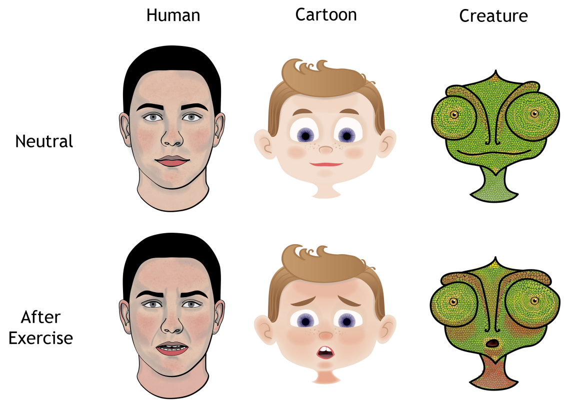


Figure 5: *Skin painting method illustrated for a human character, a cartoon and a creature. Before after exercise or neutral expression keyframes to interpolate with the after exercise flushed expressions.*

result". We have also asked the same questions to Scot Andreason (currently lead texture artist at the aforementioned videogame company) who replied: *"Really, more so than speed, this tutorial will assuredly create better accuracy"*.

5. Conclusions

We have presented a skin color painting method to assist artists animate flushing due to exertion. Our model was built from skin color measurement and analysis of 34 human subjects' photos. Color measurements were made in L*a*b* color space to obtain ΔE_{00} color changes, comparing skin color samples of before and after physical exercise. We calculated delta values separately for L*, a* and b* axis to determine color variation specifically in the a* (red to green axis), related to flushing. We have presented the delta values in an illustrated tutorial to assist artists painting the hemoglobin textures associated with physical exertion. We exemplify our method results for a human character, a cartoon and a creature. The proposed method can integrate existing texture pipelines and does not restrict artistic creativity, instead it facilitates the texture creation process, providing delta color changes to use as guidelines to render more realistic skin expressions. Our skin painting method provides parameters that may help create pre-configured color dynamic skin shading systems. A limitation of our skin capture technique is that skin reflections were not reduced completely, which in part occludes skin subsurface bloodflow. As a future direction we plan to capture skin color variations using a different setup. Future work includes further validation of the proposed method with more texture artists.

Acknowledgements

We would like to thank Fundação para a Ciência e Tecnologia for funding this research through the PhD scholarship: SFRH / BD / 51793 / 2011. We also are deeply thankful to Brandi Parish and Scot Andreason for the time taken to review the proposed method and to reply to our questions as well as to the reviewers' comments.

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