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Improved Color Compression for People with Color Blindness

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Improved Color Compression for People with Color Blindness

ABSTRACT

Color blindness is estimated to affect around 9% of the population. Streaming media requires large bandwidth due to the size of the video which depends in part on the color information in the video. This disclosure describes techniques that leverage, with user permission, a user's unique visual acuity to automatically adjust the parameters and the encoding of a video stream to incorporate suitably modified color information to reduce bandwidth and/or to improve quality of the video stream for the particular user.

KEYWORDS

- Color blindness
- Color space
- Color compression
- Video compression
- Video streaming
- Game streaming

BACKGROUND

Color blindness is estimated to affect around 9% of the population, with an estimated 2.4% of the population having just two of the three types of photoreceptor cells in the human eye. Streaming media requires significant bandwidth. Although much effort has been expended in reducing the bandwidth requirement for a given quality level (e.g., in codecs such as VP9, AV1, etc.), high bandwidth connections remain inaccessible or costly for much of the world. Live-streamed media, e.g., to a participant of a distributed multiplayer game, is typically not cached. When streaming a game, video compression or encoding is applied once and the data transmitted to one or more users and is discarded upon transmission.

DESCRIPTION

This disclosure describes techniques that leverage a user's unique visual acuity to adjust the parameters and the encoding of streaming media to reduce bandwidth usage and/or to increase quality. The user is provided with information regarding the potential benefits of the described techniques. The user is provided options that they can choose from, e.g., the user can choose to provide information regarding their visual acuity (e.g., by selecting a preferred stream from sample streams, by specifically providing information about their vision parameters, etc.) and enable the techniques; the user can decline access to such information and receive streaming media encoded with a default setting; etc.

When the user provides permission, the benefits of reduced bandwidth and increased quality are realized with no additional storage costs and with no requirements for updating video caches or using existing video caches. Effectively, the techniques of this disclosure leverage the biology of vision (e.g., that can cause color blindness) to tailor the color space of a streaming video to match the individual user's visible (differentiable) color space, thereby reducing the bandwidth needed to transmit the colors of the video to such users. While existing techniques compress and encode video and images, the techniques described herein account for an individual user's eyesight (whether that be color differentiation or otherwise), using user-permitted information provided by the individual user, to improve their experience and/or reduce data usage.

Information regarding the user's visual acuity is utilized specifically for the purpose of adjusting the video stream and is not stored, e.g., is deleted at the end of the stream. The user can alternatively choose to indicate a preference for a particular type of video compression that is used for video streams provided to the user. Such information is requested and accessed in compliance with applicable regulations. In locations where access or use of such data is not permitted, and for users that decline such information, conventional video streaming techniques are used.

Users can activate the form of compression or encoding through per-user or per-session settings, which can be ephemeral. They can also deactivate or adjust the parameters of the video compressor to cater to their unique needs and preferences. Reducing color space, per the described techniques, saves bandwidth, e.g., when the video is being transmitted to users with less than three types of photoreceptors, as the differentiable color space for such users is substantially lower than other users. The saved bandwidth can be used to improve quality in other ways, e.g., increasing resolution, frame rate, or bitrate for variable bitrate codecs. The bandwidth savings enable a better user experience in the form of increased download speeds and reduced latency.

User interface

Per the techniques of this disclosure, the user selects from options that enable them to indicate their visual acuity, e.g., choose a particular form color blindness, e.g., protanopia, deuteranopia, tritanopia, or even the rare monochromacy. With user permission, this selection is utilized for adjusting video streams. Video streams are adjusted based on indicated visual acuity, e.g., prior to initiating the stream. If the user has selected a form of supported color blindness, the stream is adjusted in such a way that the color space is reduced, with a corresponding reduction in the bandwidth necessary to transmit the stream.

An option can be provided on the selection page to enable the user to test particular color blindness settings (e.g., based on sample images/streams) and make a selection that optimally matches their visual acuity. In this manner, the user can control the modification of the video stream and verify the received video stream is satisfactory. The user can also be provided an indication of the level of benefits, e.g., reduction in latency, improved quality via higher frame rate/resolution, etc. The settings interface provides clear indication to the user that provision of such information is optional and that the information is used specifically for the purpose of adjusting the video stream.

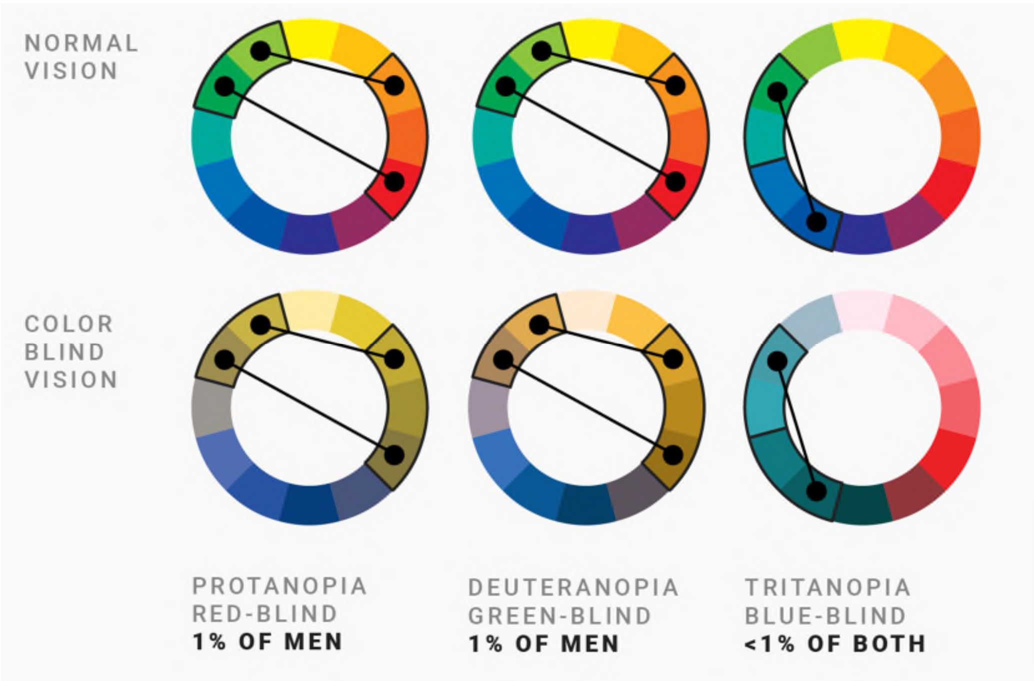

Fig. 1: A color wheel used to determine optimal compression based on the user's visual acuity (image source: https://blog.datawrapper.de/colorblindness-part2/)

Additionally, options can be provided for the user to select protanomaly, deuteranomaly, or tritanomaly as color blindness conditions. These are conditions in which one of the user's photoreceptors have diminished sensitivity. For such users, the perceivable color space is reduced, but is not equivalent to removing a standard portion of the color space. The user is provided options that enable them to convey the nature of their narrowed color space.

The user can be enabled to do so, for example, by being shown several layers of a color wheel as illustrated in Fig. 1, or equivalent, at different luminance levels and be requested to select sections that appear duplicated to their eyes. Such a test, which enables users to indicate their color perception (e.g., a color blindness condition such as protanomaly, deuteranomaly, or tritanomaly), can benefit a substantially larger number of people. In Fig. 1, individuals with a color blindness condition perceive one of the bottom circles whereas those of normal vision perceive the corresponding top circle. The sections of the color wheel that are identified by each individual user as apparently duplicated or redundant can be cut from the color space of the video stream to save bandwidth.

Color space modification to optimize a video stream

Color space modification to optimize a video stream can be accomplished in a number of different ways, as follows.

Manipulating the colors of the video to fit into the reduced color space

For example, if a user with protanopia interprets colors A_0 through to A_255 to be the same color, then any colors in the media in this range would be simplified to A_0. This technique doesn't require a new codec or color space definition; rather, it can be implemented as a pre-processing step before encoding and a post-processing step after decoding. While the technique results in compression, it functions well in already highly compressed media, e.g., media where the color space is decreased to only 256 unique colors. To forestall a decrease in quality, e.g., brightness or nearby coloring, caused by the application of the technique early in the encoding process, the color manipulation is optimally placed in the encoding process based on the specific compression algorithms and their modes of operation.

Adjusting encoding and decoding within an existing codec to take advantage of a reduced color space

For example, if a user has a form of red-green color blindness in which colors A_0 to A_255 look similar, then this technique computes for each particular block the color A_X (X being between 0 and 255) to aid compression. Such a technique can deliver a single-digit improvement, e.g., 5%, in compression. This is similar to the previous technique, but requires some insight into the functioning of the codec. Algorithms similar to the ones used in the codec can be used to determine the colors that are used to optimize the compressibility of the image/frame/video.

Creating a new color space to implement into a new or existing codec

One relatively simple way to create a new color space suited for color-blindness is to reduce the number of bits in the 24-bit Red-Green-Blue (RGB) color space used to represent a color. The number of bits reduced from a color component depends on the type of color blindness. For example, content provided to a user with impaired sensitivity to red may not need the full eight bits dedicated to red; instead, such content can use only five bits, or maybe even zero bits if the user has no red sensitivity.

Going from 24 bits per color down to only 21 or even 16 bits per distinct color, provides a 12% to 25% overall reduction in the number of bits. Note that the 25% reduction in the number of bits does not translate to a 25% reduction in bandwidth, since there is more to a video than just the color, and because compression diminishes any pre-compression benefit. Nevertheless, a significant bandwidth reduction can take place, since the color space is reduced in size and bit consumption. This technique is optimally implemented by a codec that supports arbitrary color spaces and variable fidelity in the color space. Such a codec can be implemented by modifying an existing codec to derive a new variant that supports the new color space. For example, a new profile could be added to VP9 or AV1.

Various examples of techniques of color space modification are described below.

Color space modification: lines of confusion

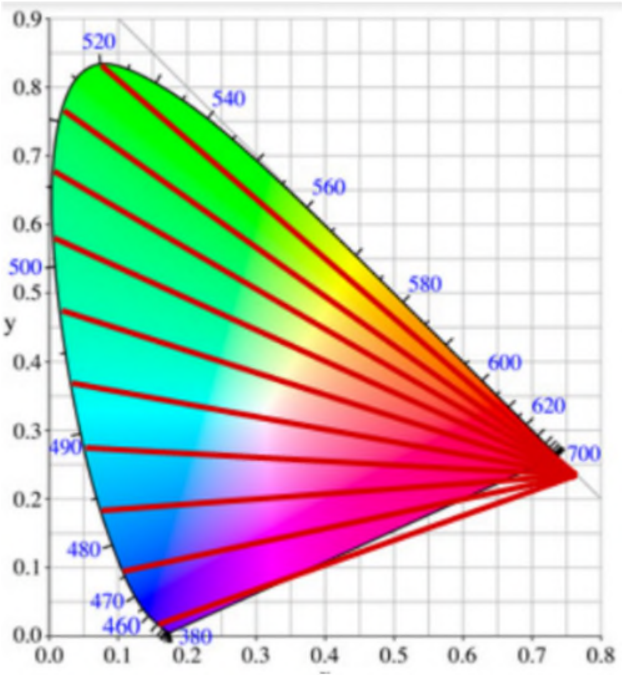

Fig. 2: Lines of confusion (image source: https://www.color-blindness.com/2009/01/19/colorblind-colors-of-confusion/)

Fig. 2 illustrates lines of confusion (red lines) superimposed on CIE-XYZ color space. For a user with protanopia (red blindness), the colors along any one red line look similar or undifferentiated. The lines of confusion for protanopia are seen to cross through areas of red and green prominence. Similarly, lines of confusion can be defined for deuteranopia (green blindness), and tritanopia (blue blindness).

The color space creation for -opia forms of color blindness (complete dysfunction of one or more photoreceptors) can be achieved by plotting a curve through the lines of confusion, which we can visualize on a color space.

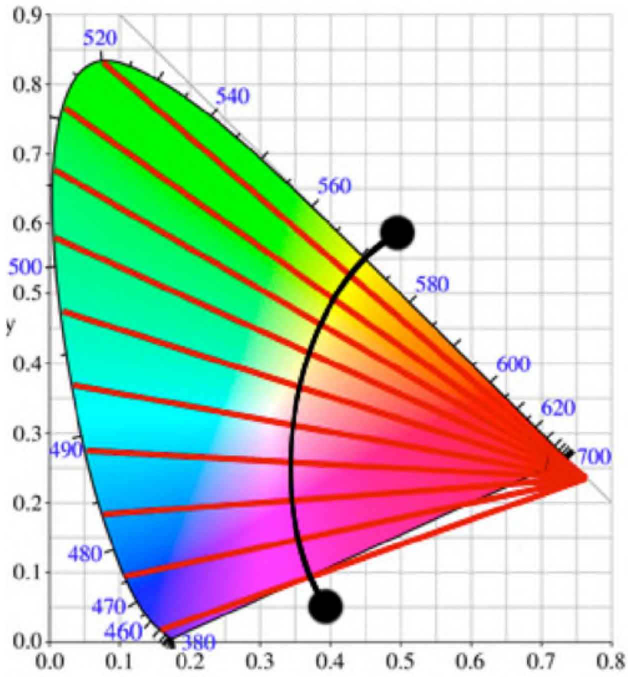

Fig. 3: Replacing a line of confusion by a point on it

This is illustrated in Fig. 3, where a curve (shown in black) is drawn perpendicular to the lines of confusion. The distance along this line is a single number that represents the particular color combination to display for the user. Effectively, a line of confusion in CIE-XYZ space is replaced by a point on it, resulting in a simplification of color space and a substantial compression of video or image data. The selected point, which replaces a line of confusion, is displayed along with a brightness or luminance value, as done normally.

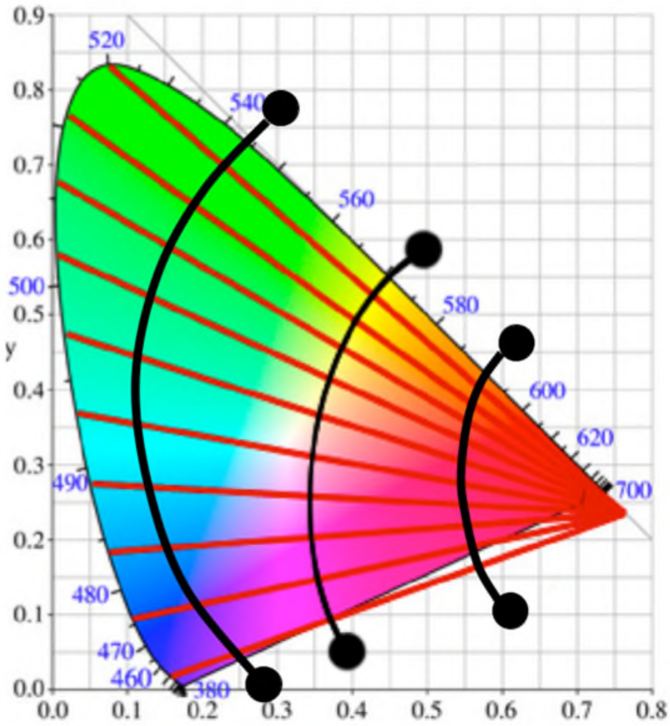

Fig. 4: Replacing a line of confusion by multiple points on it

If the user has some ability to differentiate along a line of confusion, then a second (or third) parameter could be added which is a positive or negative offset from the curve. This parameter would require few bits, so it would still save space versus an unmodified color space. Effectively, the lines of confusion are perpendicularly intersected by multiple curves, shown in black in Fig. 4, and color on a line of confusion is replaced by an intersection of the line with a curve. For example, eight bits may be allocated to brightness, eight bits to the curve, and only four bits to the confusion-line-offset from the curve for a total of twenty bits versus twenty-four bits.

Color space modification: cylindrical color spaces

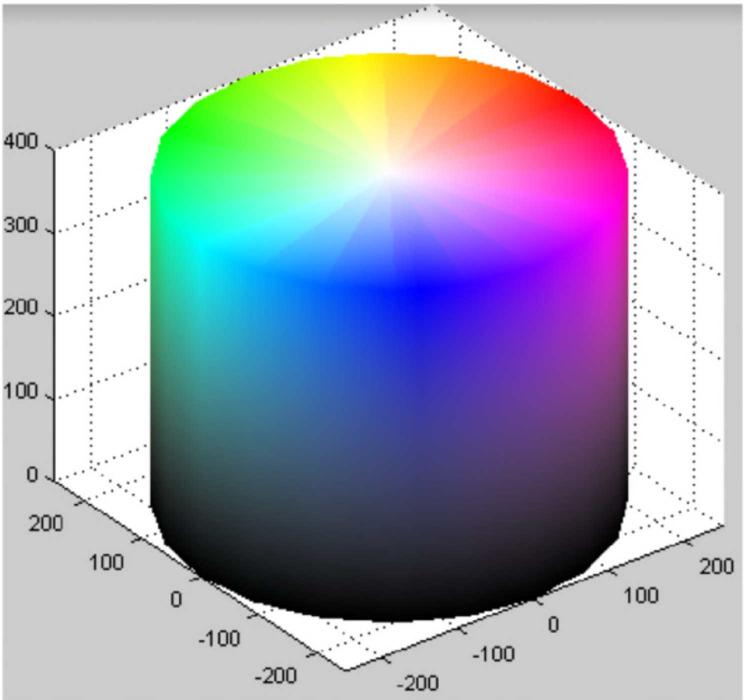

Fig. 5: A cylindrical color space (image source:
https://stackoverflow.com/questions/31523912/modeling-hsv-color-space-cylinder-in-matlab**)**

Some color spaces, e.g., HSV (hue, saturation, value), HSL (hue, saturation, light), etc., illustrated in Fig. 5, are cylindrical. In such spaces, one axis represents hue, another represents saturation, and a third represents value, which is akin to brightness. Although not shown in Fig. 5, cylindrical color spaces can have values inside of the cylinder. A point in cylindrical space can be accessed using either Cartesian (x, y, z) coordinates or cylindrical (r, h, $\boldsymbol{\varphi}$) coordinates, where r is the radius of the point from the cylindrical axis, h is the height of the point from the cylindrical base, and $\boldsymbol{\varphi}$ is the angle subtended by the point with reference the X-axis. Slicing the cylinder across a plane parallel to the XY-plane (at some height Z), results in a circle, which is effectively a color wheel at some particular luminance (height).

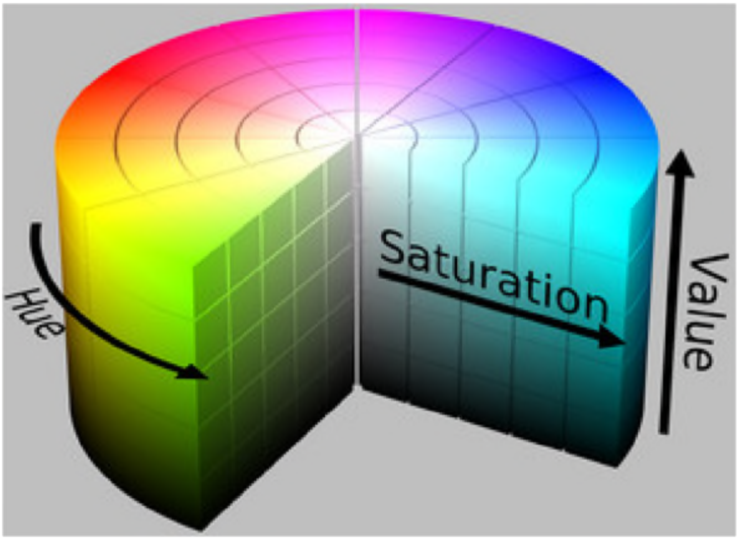

Fig. 6: Removing a wedge from a color cylinder to achieve compression for transmissions to color-blind users (image source: https://docs.opencv.org/3.4/da/d97/tutorial_threshold_inRange.html)

Colorblind individuals can be insensitive to certain hues of the color cylinder. As illustrated in the example of Fig. 6, the described techniques therefore excise wedges of the color cylinder corresponding to hues that the user is insensitive to. This is equivalent to removing a subset of the angular coordinate. For example, only the values between 45° and 315° can be retained, enabling a reduction in the number of bits used to represent the area from 45° to 315°, or the use of the same number of bits providing a greater fidelity in that range.

<u>Color space modification: YUV</u>

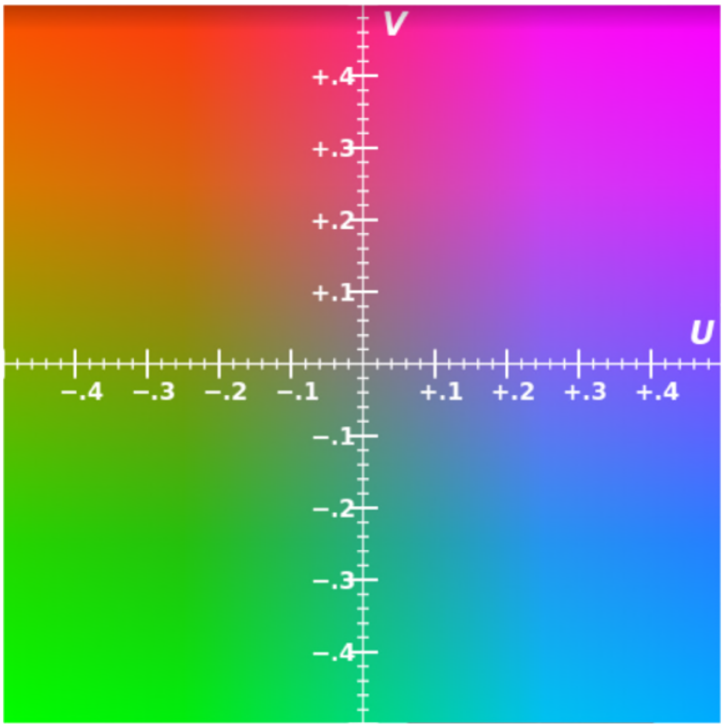

Fig. 7: The YUV color space (image source: https://en.wikipedia.org/wiki/YUV#/media/File:YUV_UV_plane.svg**)**

The YUV color-space, illustrated in Fig. 7, is a color space commonly used in digital media and codecs. Fig. 7 illustrates a slice of YUV space at a Y value of 0.5. A compression of YUV space can be achieved by substantially reducing or eliminating the storage allocated to a particular color projection, e.g., the U or the V in YUV-space. For example, individuals with red-green color blindness may not benefit much from fidelity along the V axis, enabling the allocation of just four or fewer bits to the V axis and the usual eight bits to the remaining two axes.

Other color spaces not treated herein can similarly be optimized to match an individual's visual perception. Alternatively, a color space can be created using the tools of lines of confusion and intersecting curves to match an individual's condition.

Further to the descriptions above, a user is provided with controls allowing the user to make an election as to both if and when systems, programs, or features described herein may enable the collection of user information (e.g., information about a user's color perception, a user's preferences), and if the user is sent content or communications from a server. In addition, certain data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a user's identity is treated so that no personally identifiable information can be determined for the user. Thus, the user has control over what information is collected about the user, how that information is used, and what information is provided to the user.

CONCLUSION

This disclosure describes techniques that leverage, with user permission, a user's unique visual acuity to automatically adjust the parameters and the encoding of a video stream to incorporate suitably modified color information to reduce bandwidth and/or to improve quality of the video stream for the particular user. Portions of the color information that are not perceivable by an individual user are removed from the customized stream for that user.