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| **Joint Collaborative Team on Video Coding (JCT-VC)**  **of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11**  26th Meeting: Geneva, CH, 12–20 January 2017 | Document: JCTVC-Z0040 |

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| *Title:* | **A new tool for Color Gamut Analysis of MPEG video content** | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Information | | |
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# Abstract

Most common video applications expect video content to utilize what is commonly referred to as the video/legal video range. Until recently, it was assumed that all content used for MPEG experiments were also using this range. However, it was recently that a significant amount of MPEG material may in fact be full range video content, potentially impacting visualization as well as conversion processes that may be required for different experiments within the content of MPEG. In this contribution, we present a new tool, named GamutTest, that is part of the HDRTools package. This tool may be able to assist in the analysis of video material and in helping to identify the correct video range of the content.

# Introduction

Full range video material may utilize all digital codewords given a specific bit depth, i.e. values 0 up to 255 for 8-bit material, to represent a color sample. On the other hand, video/legal range material nominally only utilize values within a well specified range, i.e. for 8-bit data the range of 16 to 235 for Y’, R’, G’, and B’ data, and 16 to 240 for Cb and Cr data. Word values outside these ranges are considered as underflow and overflow ranges. The video/legal range concept has deep roots in analog video and on how signals were handled in older television transmitters and receivers. The majority of consumer video applications expect only video range material especially when using the Non-Constant Luminance YCbCr format. Full range and Video range material essentially require different equations to be used when converting the data for display or for any subsequent processing. Incorrect conversions may result in color and contrast loss issues, that can be considered unacceptable by a user, while there could be other issues when unconditionally mixing different material types.

It was recently identified that several of the video material used for MPEG experiments might be utilizing the full range instead of the more common, video range. Although this did not likely have in the past any consequences in terms of encoding of the material, subjective tests may have been impacted if the improper conversion for display was used. Furthermore, it is now desired in new MPEG tests to convert existing material into different formats, including the PQ encoded BT.2020 Non-Constant Luminance YCbCr format (BT.2100). Such conversions would also require proper knowledge of the video format. Early identification of video or full range material was based only on the analysis of the digital values and on whether these values exceeded the defined ranges. Unfortunately, even though that could allow identifying whether some video sequences are in full range, it cannot guarantee that video sequences that may appear to be in video range are truly within.

For this purpose, we have developed a new tool, named GamutTest, that can perform additional operations on the color sample values, and could potentially better assist in the identification of the actual range of the video material. This new tool is part of the HDRTools software package.

# GamutTest tool

The GamutTest tool utilizes the common library of the HDRTools [1] package for all I/O operations. It then computes and reports statistics relating to every frame in a video sequence, that may help determine whether a sequence is in full or video range.

More specifically, after reading a video frame, GamutTest analyzes every color sample to find the minimum and maximum value for each plane. Furthermore, given a user specified video format, it computes how many sample values for each color plane are in the underflow or overflow range, as was done previously for analysing MPEG material. However, at this stage, GamutTest also performs a conversion from YCbCr to RGB and computes how many RGB values are also out of Gamut. Out of Gamut values in RGB are values that are either negative or above 1.0. This information is much more reliable than examining the digital range of the YCbCr data.

The conversion of YCbCr data to RGB involves knowledge of not only the video range but also of the color primaries of the content. Furthermore, YCbCr data commonly include chroma subsampling. Therefore, the conversion also involves an upconversion of the chroma plane. Currently this is done using the nearest neighbor interpolation process. Identifying the range may involve running the GamutTest tool on a particular video material while specifying different format parameters and determining the ones that appears to best fit the content within range.

Table 1 presents the average GamutTest analysis statistics for the first 10 frames of the SJTU test set assuming a BT.709 [2] video signal using the video range representation. The first 6 columns show the “average” minimum and “average” maximum code values encountered in these video sequences and the next 6 columns how many time these values did not satisfy the video range limits. At first look, it seems that these sequences are likely video range sequences since they either never or at least infrequently do not satisfy the video range limits. However, when looking at the RGB numbers one can observe that, using this representation, the content seems to have a rather significant number of code values that are outside of the legal RGB range. For sequence CampFireParty, even close to 20% of the green and red values go out of gamut. Instead, as shown in Table 2, if the representation is assumed to be in the Full Range representation the video sequences seem to be in gamut for almost all cases. This seems to suggest that maybe these video sequences were converted to YCbCr assuming a Full Range representation, but were clipped later given the video/legal range codeword limits. Unfortunately, such a process does not result in video/legal data. The data are still full range data with some of the bottom and higher values clipped.

We have performed a similar analysis on two other, more commonly used, sequences, sequences Kimono and ParkScene (Table 3). Even though there are a few pixels that may go out of gamut for these material, their percentages suggest that these are more likely due to processing and not due to the format of the content.

Table 1**: GamutTest analysis of the SJTU video content assuming BT.709 Video range video (8294400 pixels per picture)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **dY** | | **dU** | | **dV** | | **countY** | | **countU** | | **countV** | | **countAll** | | **countR** | | **countG** | | **countB** | | **countRGB** | |
|  | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** |
| *BundNightscape* | 66 | 945 | 65 | 871 | 65 | 963 | 0 | 28127 | 0 | 0 | 0 | 132 | 0 | 28259 | 6361 | 156371 | 0 | 29126 | 48192 | 30587 | 54442 | 159848 |
| *CampfireParty* | 66 | 945 | 65 | 780 | 69 | 963 | 0 | 94681 | 0 | 0 | 0 | 25 | 0 | 94706 | 1260 | 1491284 | 0 | 104199 | 1585638 | 80740 | 1586879 | 1491425 |
| *ConstructionField* | 101 | 945 | 348 | 691 | 264 | 712 | 0 | 12614 | 0 | 0 | 0 | 0 | 0 | 12614 | 3665 | 17068 | 0 | 12749 | 0 | 13304 | 3665 | 18434 |
| *Fountains* | 70 | 945 | 227 | 693 | 216 | 814 | 0 | 19101 | 0 | 0 | 0 | 0 | 0 | 19101 | 2073 | 67151 | 0 | 19402 | 502 | 19287 | 2575 | 67683 |
| *Library* | 66 | 945 | 260 | 709 | 242 | 789 | 0 | 9328 | 0 | 0 | 0 | 0 | 0 | 9328 | 4860 | 372548 | 0 | 12680 | 96 | 9322 | 4956 | 372690 |
| *Marathon* | 69 | 945 | 66 | 847 | 171 | 880 | 0 | 18985 | 0 | 0 | 0 | 0 | 0 | 18985 | 25589 | 48593 | 0 | 20123 | 1153 | 94573 | 26742 | 123052 |
| *ResidentialBuilding* | 71 | 945 | 181 | 700 | 146 | 898 | 0 | 194522 | 0 | 0 | 0 | 0 | 0 | 194522 | 5175 | 575990 | 0 | 199694 | 1186 | 188485 | 6360 | 576564 |
| *Runners* | 66 | 945 | 65 | 752 | 201 | 854 | 0 | 9242 | 0 | 0 | 0 | 0 | 0 | 9242 | 23796 | 12225 | 0 | 9226 | 43751 | 16192 | 67544 | 18994 |
| *RushHour* | 75 | 945 | 261 | 962 | 264 | 804 | 0 | 98843 | 0 | 1 | 0 | 0 | 0 | 98844 | 3654 | 127678 | 0 | 99966 | 610 | 123046 | 4264 | 148476 |
| *Scarf* | 70 | 945 | 108 | 881 | 171 | 863 | 0 | 23798 | 0 | 0 | 0 | 0 | 0 | 23798 | 4033 | 168767 | 0 | 25052 | 825 | 46021 | 4858 | 192112 |
| *TallBuildings* | 154 | 945 | 151 | 727 | 151 | 822 | 0 | 79724 | 0 | 0 | 0 | 0 | 0 | 79724 | 6791 | 225624 | 0 | 88577 | 30 | 73105 | 6822 | 228472 |
| *Traffic Flow* | 80 | 945 | 234 | 696 | 264 | 730 | 0 | 53065 | 0 | 0 | 0 | 0 | 0 | 53065 | 2842 | 85346 | 0 | 52234 | 318 | 72302 | 3160 | 98482 |
| *Traffic and Building* | 66 | 945 | 339 | 790 | 218 | 872 | 0 | 9569 | 0 | 0 | 0 | 0 | 0 | 9569 | 55835 | 9462 | 0 | 9742 | 0 | 19670 | 55835 | 19742 |
| *Tree Shade* | 66 | 945 | 119 | 739 | 154 | 865 | 0 | 11912 | 0 | 0 | 0 | 0 | 0 | 11912 | 1601 | 14539 | 0 | 12183 | 131680 | 11807 | 133277 | 14816 |
| *Wood* | 86 | 945 | 289 | 753 | 71 | 786 | 0 | 1488707 | 0 | 0 | 0 | 0 | 0 | 1488707 | 6878 | 1655963 | 0 | 1502407 | 283 | 1694247 | 7161 | 1785734 |

Table 2**: GamutTest analysis of the SJTU video content assuming BT.709 Full range video (8294400 pixels per picture)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **dY** | | **dU** | | **dV** | | **countY** | | **countU** | | **countV** | | **countAll** | | **countR** | | **countG** | | **countB** | | **countRGB** | |
|  | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** |
| *BundNightscape* | 66 | 945 | 65 | 871 | 65 | 963 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 446 | 1691 | 0 | 0 | 0 | 0 | 446 | 1691 |
| *CampfireParty* | 66 | 945 | 65 | 780 | 69 | 963 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 135 | 0 | 0 | 0 | 0 | 7 | 135 |
| *ConstructionField* | 101 | 945 | 348 | 691 | 264 | 712 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Fountains* | 70 | 945 | 227 | 693 | 216 | 814 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Library* | 66 | 945 | 260 | 709 | 242 | 789 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Marathon* | 69 | 945 | 66 | 847 | 171 | 880 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| *ResidentialBuilding* | 71 | 945 | 181 | 700 | 146 | 898 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 1 |
| *Runners* | 66 | 945 | 65 | 752 | 201 | 854 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *RushHour* | 75 | 945 | 261 | 962 | 264 | 804 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Scarf* | 70 | 945 | 108 | 881 | 171 | 863 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| *TallBuildings* | 154 | 945 | 151 | 727 | 151 | 822 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| *Traffic Flow* | 80 | 945 | 234 | 696 | 264 | 730 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Traffic and Building* | 66 | 945 | 339 | 790 | 218 | 872 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tree Shade* | 66 | 945 | 119 | 739 | 154 | 865 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| *Wood* | 86 | 945 | 289 | 753 | 71 | 786 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 58 | 0 | 0 | 0 | 0 | 0 | 58 | 0 |

Table 3**: GamutTest analysis of the Kimono and ParkScene video content assuming BT.709 Video range video (2073600 pixels per picture)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **dY** | | **dU** | | **dV** | | **countY** | | **countU** | | **countV** | | **countAll** | | **countR** | | **countG** | | **countB** | | **countRGB** | |
|  | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** |
| *Kimono* | 70 | 940 | 288 | 654 | 338 | 687 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 163 | 0 | 0 | 1009 | 0 | 1012 | 16 |
| *ParkScene* | 73 | 984 | 170 | 823 | 74 | 868 | 0 | 96 | 0 | 0 | 0 | 0 | 0 | 96 | 2 | 156 | 0 | 178 | 2543 | 137 | 2545 | 342 |

# Conclusion

A new tool, named GamutTest, is introduced in this contribution, which may help in identifying the format characteristics of the MPEG video test content. This tool and its implementation are made freely available within the HDRTools package. Preliminary tests also suggest that several of the video material used for MPEG tests may be using the full range representation instead of the previously thought video range representation. It is suggested that these findings are considered in future MPEG experiments.

# References

1. HDRTools Master branch: <https://gitlab.com/standards/HDRTools/>
2. Recommendation ITU-R BT.709-5, *Parameter values for the HDTV standards for production and international programme exchange*
3. Recommendation ITU-R BT.2100 (2016), *Image parameter values for high dynamic range television for use in production and international programme exchange.*

# Patent rights declaration(s)

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