ISO/IEC JTC 1/SC 29/WG 1
(ITU-T SG16)

Coding of Still Pictures

JBIG	**JPEG**
Joint Bi-level Image Experts Group	Joint Photographic Experts Group

TITLE: Draft Call for Proposals for a Next-Generation Image Coding Standard (JPEG XL)

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Draft Call for Proposals on Next-Generation Image Coding (JPEG XL)

Summary

The JPEG Committee has launched the Next-Generation Image Coding activity, also referred to as JPEG XL. This activity aims to develop a standard for image coding that offers substantially better compression efficiency than existing image formats (e.g. >60% over JPEG-1), along with features desirable for web distribution and efficient compression of high-quality images.

The JPEG Committee intends to publish a final Call for Proposals (CfP) following its 78th meeting (January 2018), with the objective of seeking technologies that fulfil the objectives and scope of the Next-Generation Image Coding activity.

This document is a draft of the CfP, and is offered for a public review period ending 19 January 2018. Comments are welcome and should be submitted to the contacts listed in Section 10.

1. Background

1.1 Introduction

The need for efficient image compression is self-evident, when taking into account that hundreds of millions of images are captured, created, uploaded, and shared daily. Applications are becoming increasingly image-rich, and websites and user interfaces (UIs) rely on images for sharing experiences and stories, visual information and appealing design.

On the low end of the spectrum, UIs can target devices with stringent constraints on network connection and/or power consumption. Even though network download speeds are improving globally, in many situations and locations bandwidth is constrained to speeds that inhibit responsiveness in applications.
On the high end, UIs utilize images that have larger resolutions and higher bit depths, and the availability of a wide color gamut is a benefit for vivid color imagery. In general, there is a growing tendency towards higher-resolution images and higher bit depths, leading to a further explosion of image data.

For most of these applications, JPEG-1, PNG and WebP are still used as the primary encoding formats. More efficient compression will benefit the described applications, and will lead to reduced network transmission times and more interactive applications.

When compared to video data, images can be stored with relatively few bits. Still, websites and UIs can contain hundreds of images, or several high-resolution images, leading to several megabytes worth of data – which could be equivalent to more than a minute of video. While video streams can be buffered before playback, image-based UIs have to be responsive and interactive, without several seconds of loading and interruption when downloading or scrolling.

Newer image formats with more efficient compression performance than JPEG-1 have been developed over the last decades, but these formats have shortcomings with respect to the targeted use cases.

Recently, evidence has been presented of compression technology that significantly outperforms other image coding standards in common use. For example, in the conclusions of the Grand Challenge comparisons held at the Picture Coding Symposium (PCS 2015) [1] and the IEEE Conference on Image Processing (ICIP 2016) [2], it was reported that "there is evidence that significant improvements in compression efficiency can be obtained using latest state of the art in lossy and lossless cases". Several metrics showed the HEVC HM encoder with SCC extensions [3] to be superior according to most metrics, and for most test images. Subjectively, Daala [4] was competitive, with a limited difference in MOS scores between HEVC and Daala. Despite these technical advances, no widespread standard is available that has state-of-the-art compression performance, and is widely supported in consumer devices and browsers.

This new JPEG activity aims to develop a new image coding standard that provides state-of-the-art image compression performance, and that addresses shortcomings in current standards. To encourage widespread adoption, an important goal for this standard is to support a royalty-free baseline.

1.2 Scope

The next-generation image coding activity aims to develop an image coding standard that offers:

- Significant compression efficiency improvement over coding standards in common use at equivalent subjective quality, e.g. >60% over JPEG-1.

- Features for web applications, such as support for alpha channel coding and animated image sequences.
- Support of high-quality image compression, including higher bit depth coding and support of wide color gamut coding.

2. Timeline

The intended timeline for the evaluation of the proposals is the following:

29/01-02/02/2018	WG1 meeting: Final Call for Proposals issued
04/2018	Objective and subjective evaluation of the anchors
16-20/04/2018	WG1 meeting: review of anchor evaluation results and agreement on final test set and evaluation procedures
01/05/2018	Deadline for indication of interest and registration – send emails to the people listed in Section 10
01/06/2018	Deadline for submission of binaries, algorithm description and design, and encoded-decoded test material
06/2018	Objective and subjective evaluation of proposals and anchors
09-13/07/2018	WG1 meeting. Assessment of technical proposals and objective/subjective evaluation results (attendance of proponents to the meeting is required).
10/2018	WG1 meeting. Issue the Verification Model description and source code.

The intended timeline for the standardization process is as follows:

2018/10	WD1
2019/01	WD2
2019/04	CD
2019/07	DIS
2020/01	FDIS/IS

The above schedule is subject to change, depending on the nature of proposals that are received and the possible need to integrate or merge elements from different proposals.

3. Use Cases

This section presents a list of use cases that motivate the need for a new image coding standard.

3.1 Image-rich UIs and web pages on bandwidth-constrained connections

Web sites and user interfaces become more and more image-driven. Images play a major role in the interaction between users, the selection of topics, stories, movies, articles and so on. In these UIs, formats are preferred that are widely supported in browsers and/or CE devices, such as JPEG-1, PNG and WebP.

3.1.1 Social media applications

Millions of user-generated images are captured and uploaded daily. After uploading, the images are typically converted into multiple quality versions and formats and stored on content delivery network (CDN) servers. More efficient image compression will aid to distribute social media images to users worldwide, including to locations with limited connectivity or low-bandwidth mobile connections. Image formats need to be supported that are widely supported on consumer devices, such as smartphones and tablets, and on browsers. Compression efficiency is key in delivering the images to devices over low-bandwidth connections, and in making the UIs and web sites as responsive as possible.

3.1.2 Media streaming applications

In the case of video and audio distribution applications, UIs and web sites will contain a wide array of artwork images that will guide users through the catalog. Images are typically derived from high-quality studio shots, artwork or movie/show masters. Derived images can include natural and synthetic images, transparent overlays, multilingual text, animation, gradients etc. Multiple quality/resolution versions of the same image are finally encoded, and stored in the CDN. The UIs can contain hundreds of images, ranging from small thumbnail-like images to screen-spanning billboard images.

3.1.3 Cloud storage applications

Cloud storage applications will amass a huge amount of images captured by users. After uploading, these images will be stored on servers, possibly after a lossless transcoding operation [5]. Still, for visualization and timeline-style thumbnail generation, lossy transcoding can be performed to more efficient formats, lower resolutions, and preview images. For this downstream-oriented traffic, more efficient formats are desirable.

3.1.4 Media web sites

Images are captured by news agencies, journalists and users, and will be selected for publication on media web sites. Images can range from high resolution to thumbnail-size, resulting in sites that contains megabytes worth of images.

3.1.5 Animated image applications

For increased interactivity and expressing emotions, animated image sequences have become very popular. The wide majority of animated image sequences currently rely on the GIF image format, which suffers from inefficient compression and a limited color palette.

3.2 High-quality images applications

On the high end, UIs utilize images that have larger resolutions and higher bit depths, and the availability of a wide color gamut is a benefit for vivid color imagery. 4K TVs are becoming mainstream, and HDR/WCG technology is picking up, leading to a shift to high-quality UIs.
Although these higher-end applications typically target more stable network connections, transmission of multiple high-quality images still takes a significant time on most current network connections. A new standard should provide efficient compression and high visual quality for these applications.
Images in these applications can contain a mixture of natural images and synthetic elements (overlays, multilingual text, gradients etc.). A new standard should include coding tools that can efficiently compress synthetic content while avoiding visible quality artifacts (e.g. aliasing, banding).
Furthermore, applications such as augmented reality, virtual reality, and 360 images require high-resolution images that need to be efficiently compressed. For these high-resolution images, region-of-interest coding is a desirable feature to support interactive applications.

4. Requirements

This section presents the requirements that should be met by the proposals so as to be suited for the above described use cases. Requirements are split between "core requirements" which are essential and "desirable requirements" which are nice to have and will be decided depending on its cost. The latter are not strictly required for a proposal to be accepted and evaluated. However, if some additional/optional features are present, this will be taken into account in their assessment.

4.1 Uncompressed image attributes

This CfP targets image coding technology that can at least support images with the following attributes:

- Image resolution: from thumbnail-size images up to 8K (8192×4320) and beyond
- Component subsampling: 4:2:0, 4:2:2, and 4:4:4
- Component type: RGB, YCbCr
    - Input type of the encoder shall match output type of the decoder.
    - Internal color space conversion is permitted (as part of the proposal).
- Different types of content, including natural, synthetic, and screen content.
- Bit depth: 8 and 10 bit, up to 16 bit for high quality images.

4.2 Compressed bitstream requirements

Submissions shall cover at least the core requirements, and are encouraged to cover desirable requirements as well.

Core requirements
Significant compression efficiency improvement over coding standards in common use at equivalent subjective quality.
Hardware-friendly encoding and decoding.
Support for alpha channel / transparency coding.
Support for animation image sequences.
Support for 8-bit and 10-bit bit depth.

Desirable requirements
Support for higher bit depth (e.g. 12 to 16-bit integer or floating-point HDR) images.
Support for different color representations, including Rec. BT.709, Rec. BT.2020, Rec. BT.2100, LogC.
Support for wide color gamut encoding.
Support for embedded preview images
Support for very low file size image coding (e.g. <200 bytes for 64×64 pixel images) [6].
Support for lossless alpha channel coding.
Support for efficient text and graphics compression.
Support for a low-complexity encoding option.
Support for region-of-interest coding.

5. Royalty-free goal

The royalty-free patent licensing commitments made by contributors to previous standards, e.g. JPEG 2000 Part 1, have arguably been instrumental to their success. JPEG expects that similar commitments would be helpful for the adoption of a next-generation image coding standard.

6. Call for Proposals Details

This CfP invites proponents to submit technology contributions that fulfill the scope, objectives, requirements and use cases therein. Proponents are reminded that they are expected to contribute to the standardisation process, as described in Section 7, and attend meeting and present their findings, as specified in Section 2.

6.1 Submission requirements

A submission shall consist of the elements specified in Annex A. Elements of a submission are provided according to the timeline specified in Annex A.

6.2 Evaluation of proposals

The committee plans to select technologies to be included in the standard based on satisfying the requirements and evaluating the results obtained through the evaluation procedure documented in Annex B.

6.3 IPR conditions (ISO/IEC Directives)

Proponents are advised that this call is being made in the framework and subject to the common patent policy of ITU-T/ITU-R/ISO/IEC and other established policies of these standardization organizations. The contact persons named in Section 10 can assist potential submitters in identifying the relevant policy information.

7. Contribution to Standardization

Proponents are informed that based on the submitted proposals, a standard specification will be created. If they submit a proposal and (part of) the proposed technology is accepted for inclusion in the standard, they will be expected to attend subsequent WG1 meetings and contribute to the creation of the relevant documents. Within this process, evolution and changes are possible as several technologies may be combined to obtain a better performing solution.

8. JPEG XL e-mail reflector information

E-mail reflector: jpeg-xl@listes.epfl.ch
In order to subscribe to the mailing list send an e-mail (its content is unimportant) to the address: jpeg-xl-subscribe@listes.epfl.ch. You will receive information to confirm your subscription, and upon the acceptance of the moderator will be included in the mailing list.

9. Context: other ongoing activities within JPEG

WG1 wants to emphasize the distinction between the proposed activity on next-generation image coding, and two other ongoing activities within JPEG: JPEG XS and High Throughput JPEG 2000.

9.1 Low-latency lightweight image coding system (JPEG XS)

Today's industrial applications often imply transport and storage of uncompressed images and video. This is for instance the case in video links (SMPTE Serial Digital Interface), IP transport (SMPTE ST 2022 5/6 & proprietary uncompressed RTPs), Ethernet transport (IEEE/AVB), proprietary transports, memory buffers, and omnidirectional video capture and rendering in VR applications. In this context, the JPEG committee is working on a standardization project, JPEG XS, referenced as ISO/IEC 21122, that targets a low-latency lightweight coding system aimed at supporting higher resolutions and frame rates over these channels assuring high visual quality and low latency while keeping power and bandwidth consumption within a reasonable budget. This effort will result in a highly interoperable solution.

9.2 High Throughput JPEG 2000 (HTJ2K)

WG1 has launched the High Throughput JPEG 2000 (HTJ2K) activity, which aims to develop an alternate block coding algorithm that can be used in place of the existing block coding algorithm specified in ISO/IEC 15444-1 (JPEG 2000 Part 1). The objective is to increase throughput of JPEG 2000 while otherwise maintaining its unique combination of features, including minimizing the impact of changes on existing codestream syntax and structure, implementations, workflows and content libraries. The output of HTJ2K activity is intended to be published as Part 15 of the JPEG 2000 family of specifications (ISO/IEC 15444).

10. Contacts

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ANNEX A – SUBMISSION REQUIREMENTS

The process to evaluate proposals will be done following the timeline defined in Section 2. The successive deliverables are further defined hereunder. Due dates for each deliverable will be added in the Final Call for Proposals. In addition to documents and binaries to be submitted, proponents are reminded that they are expected to contribute to the standardisation process, as described in Section 7.

A.1. Proposal overview

The proposal overview shall include:

- A high-level description of the proposal including block diagrams of encoder and decoder.
- Arguments on why the proposal is meeting the requirements.

Convenient formats include Word document, PDF format, PowerPoint presentations or example pictures.

A.2. Binary encoder and decoder executables

Proponents need to submit separate encoder and decoder executable programs (statically linked Linux executables with all required libraries and system dependencies), configurable via command line or configuration file. Binaries should preferably be optimized software meeting the performance requirements described above in order to speed up the evaluation process.
Proponents can choose to use executable compression or similar tools to prevent reverse engineering or disassembly of the submitted executable files.
Proponents shall provide the command-line parameters intended to be used for the evaluation procedures described above. Scripts for generating the test content shall also be provided for every test case. A detailed list of test material and target bitrates is provided in Section B.1.

A.3. Encoded-decoded material

Proponents need to submit the final test material processed by their coding system:

- Encoding-decoding results
- Encoded-decoded material for subjective evaluation.

A.4. Algorithm and design description

Each proposal shall include a presentation that provides a detailed description of the proposed algorithm and codec design. This presentation shall be in Word document and PDF format. The presentation shall clearly explain how the proposed algorithm meets the requirements described above: quality, complexity, and additional features.

A.5. Technical documentation

If (part of the) the proposal has been selected to be part of the upcoming standard, a technical description of the selected technology shall be provided. This includes:

- Description of operations, as described in algorithm and design description
- Coded bitstream syntax
- Coding process (encoding and decoding) methodology.

The description shall include all necessary processing (including performance optimizations) that are used to create the bitstream in a bit-exact manner.

A.6. Complexity analysis

Proponents are invited to submit an evaluation of the complexity of their algorithm. Such evaluation shall include:

- A detailed block diagram of the proposed encoder/decoder showing the algorithmic blocks and flow of the data.
- An explanation of the achievable parallelism of the algorithmic blocks for both the encoder and the decoder.
- All information available at the time of submission showing the performance of the encoder and decoder once implemented in software (including overall encoding/decoding time, encoding/decoding time per algorithmic block, memory usage).

A.7. Verification model source code

Proponents agree to release source code to serve as a Verification Model (VM), written in a high-level language, such as C or C++, if parts of their technology are selected in the evaluation process. Source code shall be documented and understandable. Assembly language or GPU code is not permitted. All libraries used by the source code shall be either public or provided in source code form with ISO/IEC and ITU-T compliant terms.
Make files or project files need to support compilation on both Windows and Linux systems. The VM decoder should correctly decode any codestream generated by the submitted encoder executable binary. Moreover, the VM decoder and the submitted decoder executable binary shall both generate the exact same output.

ANNEX B – EVALUATION PROCEDURES

B.1. Test material

B.1.1. General

Test material consists of the still images detailed in Section B.1.2. All test material has been converted to the required input format and is made available to proponents on an FTP server for the purpose of this standardisation project only. Proponents shall email the contacts listed in Section 10 to receive the login information required to access the test images, together with copyright information related to this test material.

B.1.2. Image Data

A set of test images will be made available to proponents, which will include images used in previous comparisons, e.g. [8]. Test images will include natural, synthetic (e.g. graphics, text, logos), screen captured content, and combinations of these (e.g. text overlaid on natural images).

A full list of the used images is provided in the following table:

Class A: Natural images (color)	Class B: Natural images (grayscale)
- ARRI_Lake2_2880x1620p_24_8b_bt709_444_0000.ppm - ARRI_PublicUniversity_2880x1620p_24_8b_bt709_444_0000.ppm - BIKE_2048x2560_8b_RGB.ppm - bike3.ppm - bird_of_paradise.ppm - CAFE_2048x2560_8b_RGB.ppm - EBU_PendulusWide_3840x2160p_50_10b_bt709_444_0001.ppm - FemaleStripedHorseFly_1920x1080_8b.ppm - HDCA_set2_0000_0000.ppm - HDCA_set6_0000_0000.ppm - HDCA_set9_0000_0000.ppm - HDCA_set10_0000_0000.ppm - HintergrundMusik_1920x1080_8b.ppm - honolulu_zoo.ppm - oahu_northcoast.ppm - p01.ppm - p04.ppm - p06.ppm	- AERIAL2_2048x2048_8b_Y.pgm - CATS_3072x2048_8b_Y.pgm - CCITT1_3504x4750_1b_Y.tif - CCITT2_3072x4352_1b_Y.tif - COMPOUND2_5120x6624_8b_Y.pgm - noise_3840x2160_12b.tif - FINGER_512x512_8b_Y.pgm - GOLD_720x576_8b_Y.pgm - HOTEL_720x576_8b_Y.pgm - MAT_1528x1146_8b_Y.pgm - SEISMIC_512x512_8b_Y.pgm - TEXTURE1_1024x1024_8b_Y.pgm - TEXTURE2_1024x1024_8b_Y.pgm - TOOLS_1524x1200_8b_Y.pgm - ULTRASOUND_512x448_8b_Y.pgm - WATER_1465x1999_8b_Y.pgm - XRAY_2048x1680_12b_Y.tif

- p08.ppm - p10.ppm - p14.ppm - p26.ppm - TOOLS_1520x1200_8b_RGB.ppm - VQEG_CrowdRun_3840x2160p_50_8b_bt709_444_07111.ppm - VQEG_ParkJoy_3840x2160p_50_8b_bt709_444_15523.ppm - noise_3840x2160_12b.tif - WALTHAM1_3600x2600_8b_RGB.tif - WALTHAM2_3800x2600_8b_RGB.tif - WOMAN_2048x2560_8b_RGB.ppm	
Class C: Computer-generated images	**Class D: Screen content images**
- BLENDER_Sintel1_4096x1744p_24_8b_sRGB_444_00003096.ppm - BLENDER_Sintel2_4096x1744p_24_10b_sRGB_444_00004606.ppm - BLENDER_TearsOfSteel_4096x1714p_24_12b_sRGB_444_01290.ppm	- APPLE_BasketBallScreen_2560x1440p_60_8b_sRGB_444_000.ppm - HUAWEI_ScMap_1280x720p_60_8b_sRGB_444_000.ppm - RICHTER_ScreenContent_4096x2160p_15_8b_sRGB_444_0001.ppm
Class E: HDR/WCG images	**Class F: Animated images**
- ARRI_AlexaDrums_3840x2160p_24_12b_logC_444_00000.ppm - ARRI_AlexaDrums_3840x2160p_24_12b_P3_444_00000.ppm - ARRI_AlexaHelicopterView_3840x2160p_24_12b_logC_444_00000.ppm - ARRI_AlexaHelicopterView_3840x2160p_24_12b_P3_444_00000.ppm	To be added
Class G: Natural images with overlays (text, logos etc)	
To be added	

B.1.3. Anchors

Proposals will be compared against the following anchors:

- JPEG-1 (ISO/IEC 10918-1 \| ITU-T Rec. T.81)
- JPEG 2000 (ISO/IEC 15444-1 \| ITU-T Rec. T.800)
- HEVC (ISO 23008-2:2015 \| ITU-T Rec. H.265 (v4))

- WebP [9].

Information on available software and configurations to be used for these anchors is given in Annex C.

B.1.4. Evaluation procedures

Objective and subjective quality evaluation of the proposals will each be done by at least two independent labs, following procedures described hereunder in Sections B.1.4.2 and B.1.4.3, and based on the encoded-decoded test material provided by each proponent. Submitted binaries will be used for verification purposes.

For objective quality testing, evaluation tools described in Annex B.1.5 are made available freely to let proponents perform their own assessments. In the evaluation procedures described hereunder, definitions in Annex D are used.

B.1.4.1. Target rates

Target bitrates for the *objective* evaluations include 0.12, 0.25, 0.50, 0.75, 1.00, 1.50, and 2.00 bpp.
Target bitrates for the *subjective* evaluations will be a subset of the target bitrates for the objective evaluations, and will depend on the complexity of the test images.

B.1.4.2. Objective quality testing

Objective quality testing shall be done by computing several quality metrics, including PSNR, MS-SSIM, FSIM, VIF, and VMAF between compressed and original image sequences, at the target bitrates mentioned in Section B.1.4.1.

B.1.4.3. Subjective quality testing

Subjective quality evaluation of the compressed images will be performed on test images described in Section B.1.2. The methodology will be based on absolute category rating with hidden reference (ACR-HR), with a randomized presentation order, as described in ITU-T P.910 [7]. As anchors, JPEG-1, WebP, HEVC, and JPEG 2000 will be used. The final modalities for subjective testing will be decided at the 79th JPEG meeting in La Jolla.

B.1.5. Evaluation tools

To ease the objective assessment of the different proposals, a set of tools will be developed (in Bash and Matlab) to automatically perform the objective assessment of a given set of codecs. Its features will include:

- Automatic installation script: the tool automatically downloads and configures all anchors codecs.
- Easy addition of new (proprietary) codecs by placing binaries in an appropriate folder.
- Supported input format: ppm for RGB content and YUV planar for YCbCr content.
- Easy addition of new test sequences.

- Encoding and decoding run.
- Objective metrics: PSNR, MS-SSIM, FSIM, VIF, and VMAF (Matlab required).
- Automatic generation of graphs based on results (Matlab required).

The tools only run on Linux/Mac platforms.

ANNEX C – ANCHOR CONFIGURATION

C.1. JPEG (ISO/IEC 10918-1 | ITU-T Rec. T.81)

- Configuration
  - JPEG does not specify a rate allocation mechanism allowing to target a specific bitrate. Hence, an external rate-control loop is required to achieve targeted bitrate.
  - Irreversible RGB to YCbCr conversion has to be disabled when dealing with YCbCr content
  - Subsampled content (i.e. 4:2:2) is first upsampled to 4:4:4 before being encoded. The decoded content is then downsampled to 4:2:2 before PSNR is computed.

- Available software: JPEG XT Demo Codec v1.51 (GPL v3)
  - Available at http://jpeg.org/jpegxt/software.html.
  - License: GPLv3
  - Only supports 8 bpc and 12 bpc content
  - Command-line examples (to use within rate-control loop)
    - RGB

      jpeg -q [QUALITY_PARAMETER] [INPUTFILE] [OUTPUTFILE]
    - YCbCr

      jpeg –c -q [QUALITY_PARAMETER] [INPUTFILE] [OUTPUTFILE]

C.2. JPEG 2000 (ISO/IEC 15444-1 | ITU-T Rec. T.800)

- Configuration
  - Two configurations
    - PSNR-optimized
    - Visually optimized
  - A target rate can be specified using the –rate [bpp] parameter.
- Available software: Kakadu, v7.10.2
  - Available at http://www.kakadusoftware.com.
  - License: demo binaries freely available for non-commercial use
  - Command-line examples:
    - PSNR-optimized: kdu_compress -i [INPUTFILE] -o [OUTPUTFILE] –rate [BPP] -no_weights
    - Visually: kdu_compress -i [INPUTFILE] -o [OUTPUTFILE] –rate [BPP] -rgb_to_420

C.3. HEVC (ISO 23008-2:2015 | ITU-T Rec. H.265 (V3))

- Configuration:
  - An external rate-control loop is required to achieve targeted bitrate.
  - encoder_intra_main_rext.cfg to allow for 4:4:4 and 4:2:2 content
- Available software: HEVC Test Model (HM)
  - Available at https://hevc.hhi.fraunhofer.de/

  - License: BSD
  - Configuration files to be used will be available in the repository of the evaluation tools described in Annex B.1.5.

C.4. WebP

- Configuration:
  - An external rate-control loop is required to achieve targeted bitrate.
- Available software: WebP
  - Available at https://developers.google.com/speed/webp/download
  - License: Apache License, Version 2.0
  - Only supports 4:2:0 output
  - Command-line example (to use within rate-control loop)
    - YCbCr

```
cwebp –m 6 -q [QUALITY_PARAMETER] [INPUTFILE] –o [OUTPUTFILE]
```

ANNEX D – DEFINITIONS

D.1. Mean Square Error (MSE)

For a given image component C of size $W\times H$, the Mean Square Error (MSE) between this original image component C and the encoded and decoded image C' is given by:

$$MSE_{C'} = \frac{\sum_{i=0}^{W-1}\sum_{j=0}^{H-1}\left(C(i,j) - C'(i,j)\right)^2}{W.H}$$

For a given image I made of three components C_1, C_2 and C_3, without chroma subsampling (4:4:4), the Mean Square Error (MSE) between this original image I and the encoded and decoded image I' is given by:

$$MSE_{I'} = \frac{\sum_{k=0}^{3} MSE_{C'_k}}{3}$$

For a given image I made of 3 components Y, C_b and C_r, with 4:2:2 chroma subsampling, the Mean Square Error (MSE) between this original image I and the encoded and decoded image I' is given by:

$$MSE_{I'} = \frac{MSE_{Y'}}{2} + \frac{MSE_{C'_b}}{4} + \frac{MSE_{C'_r}}{4}$$

For a given sequence S made of N images, the average $MSE_{S'}$ over the whole sequence is given by:

$$MSE_{S'} = \frac{\sum_{L=0}^{N-1} MSE_{L'}}{N}$$

D.2. Peak Signal-to-Noise Ratio (PSNR)

For a given image I with a maximum component sample value of B, the Peak Signal-to-Noise Ratio (PSNR) between this original image I and the encoded and decoded image I' is given by:

$$PSNR_{I'} = 10.\log\left(\frac{(2^B - 1)^2}{MSE_{I'}}\right)$$

D.3. Target bitrate and bits per pixel (bpp)

The target bit-rate for objective and subjective quality experiments is given in “bits per pixel”. For a given compressed image, the bit-rate in bits per pixel (bpp) is given by the length of the compressed image (in bits) divided by the number of pixels in the original image. If the original image is a chroma-subsampled image, the number of pixels corresponds to the number of samples in the Y component.

ANNEX E – REFERENCES

[1] M. Bernando, T. Bruylants, T. Ebrahimi, K. Fliegel, P. Hanhart, L. Krasula, A. Pinheiro, M. Rerabek, P. Schelkens, and H. Xu, "Objective and Subjective Evaluations of Some Recent Image Compression Algorithms", https://people.xiph.org/~unlord/PCS2015/PCS2015.pdf, Picture Coding Symposium (PCS), Cairns, Australia, June 2015.

[2] E. Alexiou, I. Viola, L. Krasula, T. Richter, T. Bruylants, A. Pinheiro, K. Fliegel, M. Rerabek, A. Skodras, P. Schelkens and T. Ebrahimi, "Overview and Benchmarking Summary for the ICIP 2016 Compression Challenge", http://www.slideshare.net/touradj_ebrahimi/icip2016-image-compression-grand-challenge-66475960, IEEE Conference on Image Processing (ICIP), Phoenix, USA, September 2016.

[3] J. Lainema, M. M. Hannuksela, V. K. Malamal Vadakital, and E. B. Aksu, "HEVC Still Image Coding and High Efficiency Image File Format", IEEE Conference on Image Processing (ICIP), Phoenix, USA, September 2016.

[4] J.-M. Valin, "Daala: a Perceptually-Driven Still Picture Codec", IEEE Conference on Image Processing (ICIP), Phoenix, USA, September 2016.

[5] D. R. Horn (Dropbox), "Lepton image compression: saving 22% losslessly from images at 15MB/s", https://blogs.dropbox.com/tech/2016/07/lepton-image-compression-saving-22-losslessly-from-images-at-15mbs/.

[6] B. K. Cabral and E. Kandrot, "The Technology Behind Preview Photos", Facebook Code, https://code.facebook.com/posts/991252547593574/the-technology-behind-preview-photos/.

[7] ITU-T P.910, "Subjective video quality assessment methods for multimedia applications", April 2008.

[8] "Image Compression Grand Challenge at ICIP 2016", https://jpeg.org/items/20151126_icip_challenge.html

[9] "A New Image Format for the Web", https://developers.google.com/speed/webp/