On the assessment of high-quality images: advances on the JPEG AIC-3 activity

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ABSTRACT

Recent advances in image compression have made it both possible and desirable for image quality to approach the visually lossless range. However, the most commonly used subjective visual quality assessment protocols, e.g. those reported in ITU-T Rec. BT.500, are ineffective in evaluating images with visual quality between high to nearly visually lossless. In this context, the JPEG Committee has initiated a renewed activity on the Assessment of Image Coding, also referred to as JPEG AIC, aiming at standardizing new subjective and objective image quality assessment methodologies applicable in the quality range from high to nearly visually lossless. For this purpose, a Call for Contributions on Subjective Image Quality Assessment was issued with a deadline in April 2023, and a Call for Proposals on Objective Image Quality Assessment is expected to be issued in the near future. This paper aims at providing an overview of submissions to the Call for Contributions and present the recent advances of this activity, as well as its future directions.

Keywords: Image quality assessment, image compression, JPEG AIC, subjective quality assessment, objective quality metrics

1. INTRODUCTION

Assessment of perceptual visual quality of images remains a critical topic in multimedia signal processing and is applied through the entire image processing pipeline: starting from capturing and reconstructing, all the way to rendering pictures on monitors or printing. Especially important, however, is to assess visual quality in image compression that is not mathematically lossless, also known as lossy image compression. In fact, most of the image compression technologies widely used today cannot reconstruct a mathematically exact copy of a compressed image, but can only produce an output visually similar to the original. Thus, the level of this similarity, as well as the general appeal of the images, need to be measured. Image quality assessment is divided into two main categories: subjective and objective. The former utilizes psycho-visual statistical trials to gather and aggregate subjective opinions of human observers and produce a numerical representation of visual perception of similarity between an original and impaired image. Whilst, the latter intends to closely estimate human perception with mathematical models and algorithms.

With advances in scientific research and maturing of research-derived technologies, the stakeholders from relevant industries begin to incorporate these methodologies for developing their products and services. In that view, international standardization allows the global industry to agree on the most suitable methods and approaches to be used. Previous standardization efforts have resulted in a number of standards to address the problem of image quality assessment. Notably, the existing and widely accepted standards are: BT.500[1] and AIC-1[2] for subjective image quality assessment of images in the low to high-quality range, and AIC-2[3] for assessing visually lossless image quality. The above standards, however, only focus on image qualities in the ranges of low to high or visually lossless as depicted in Figure 1. Thus, there exists a gap between the high and nearly visually lossless quality range, that will be covered by the new upcoming JPEG AIC-3 standard.

In addition to targeting subjective quality assessment methodologies, the new upcoming JPEG AIC-4 standard intends also to address the problem of measuring objective visual quality in the high to nearly visually

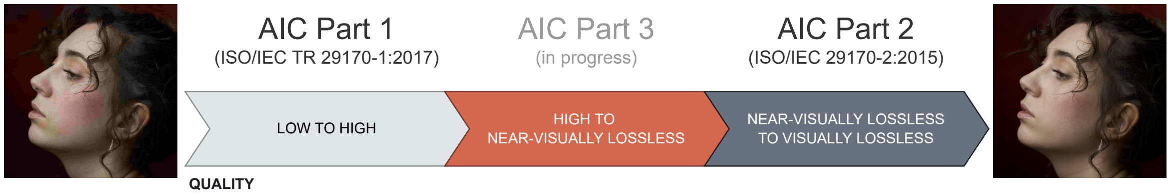


Figure 1: Previous AIC standards and covered image quality ranges.

lossless range. Objective visual quality metrics are crucial for improving the trade-offs between perceptual quality, compression density, and encoding speed and making better use of coding tools or pruning the search space. Encoders usually implement and optimize for objective metrics internally. Moreover, objective metrics are generally preferred in order to allow for faster iterations of development and fine-tuning of algorithm parameters. In this case, the computational complexity of a metric must be carefully considered since it impacts the performance of the codecs as well as the time spent in their development.

Even though, previously, objective perceptual visual quality metrics have not been usually standardized, there exist particular ones that can be considered as *de facto* standards in the industry and research community due to their wide use. The most known image quality metrics that are ubiquitously used are Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity (SSIM)[4] together with their derivatives, such as Multiscale Structural Similarity (MS-SSIM).[5] Another metric that is not as widely used, but has a better[6] performance is Visual Information Fidelity (VIF).[7] Among the most recent quality metrics, Video Multimethod Assessment Fusion (VMAF)[8] which incorporated machine learning through support vector machines is the most promising.

Nonetheless, the existing objective quality metrics tend to saturate at the high to nearly visually lossless qualities and are not performing as well on learning-based image codecs.[9] This has motivated the JPEG AIC activity in the search for new approaches to address objective assessment of perceptual visual quality.

2. OVERVIEW OF THE JPEG AIC ACTIVITY

In July 2021, JPEG Committee launched a renewed activity on the Assessment of Image Coding, also referred to as JPEG AIC. The activity has the scope to *"specify standards or best practices with respect to subjective and objective image quality assessment methodologies that cover a range from high quality to nearly visually lossless quality"*. Such quality range, in fact, was found not well covered by previous visual quality assessment methodologies, both subjectively and objectively.

Early work on the activity addressed subjective quality assessment methodologies, by reviewing the previous standards and identifying the uncovered quality gap.[10] The activity also observed that previously-standardized methodologies for subjective image quality assessment methodologies presented in ITU-R BT.500[1] are more suitable to evaluate the *visual appeal* of images other than their *fidelity* to their reference; on the other hand, the methodologies presented in the AIC-2 standard[3] are extremely sensitive to *fidelity* and are suitable to be used only in specific use cases.[11] Such observations were confirmed by the results of an exploration study,[12] which emphasized the need for new subjective image quality assessment methodologies robust in the quality range from high to nearly visually lossless. To cover this gap, the activity released a Call for Contributions on Subjective Image Quality Assessment,[13] where the collaborative process was initialized in April 2023.

In October 2023 the activity is planning to initiate the work on objective image quality metrics, by drafting a Call for Proposals on Objective Image Quality Assessment. Contrary to the Call for Contributions on Subjective Image Quality Assessment, which used a collaborative approach from the start, the Call for Proposals on Objective Image Quality Assessment will initiate with a competitive approach.

Table 1 reports the current timeline of the JPEG AIC activity, both for Part 3 of the standard (Subjective Image Quality Assessment) as well as Part 4 (Objective Image Quality Assessment).

Timeline	
97th JPEG Meeting, October 2022	Final Call for Contribution on Subjective Image Quality Assessment (Part 3)
1st April 2023	Submission of Contributions on Subjective Image Quality Assessment (Part 3)
99th JPEG Meeting, April 2023	Start of the collaborative process for Subjective Image Quality Assessment (Part 3)
101st JPEG Meeting, October 2023	Working Draft for Subjective Image Quality Assessment (Part 3)
101st JPEG Meeting, October 2023	First Draft Call for Proposals on Objective Image Quality Metrics (Part 4)
102nd JPEG Meeting, January 2024	Committee Draft (CD) for Subjective Image Quality Assessment (Part 3)
103^{ed} JPEG Meeting, April 2024	Final Call for Proposals on Objective Image Quality Metrics (Part 4)
Beginning July 2024	Submission of proposals on Objective Image Quality Metrics (Part 4)
104th JPEG Meeting, July 2024	Draft International Standard (DIS) for Subjective Image Quality Assessment (Part 3)
106st JPEG Meeting, January 2025	Working Draft for Objective Image Quality Assessment (Part 4)

Table 1: Timeline of the JPEG AIC activity.

3. JPEG AIC-3 DATASET

The JPEG AIC-3 dataset[10] * was created for the purpose of evaluation of responses to the JPEG AIC Call for Contributions on Subjective Image Quality Assessment. The dataset includes 10 high-resolution uncompressed images, with different sizes and contents. The details on the images in the dataset are available in Table 2, while a preview of the images is presented in Figure 2.

In addition to the uncompressed images, the dataset includes reconstructed images with different codecs and different quality levels. Notably, the selected codecs are JPEG 1, JPEG 2000, HEVC Intra, VVC Intra, AVIF, and JPEG XL, generated using the command lines reported in Appendix A. Each image in the dataset was compressed with all above codecs at 10 different quality levels, targeting equal Just Noticeable Difference (JND) values in the range between -0.25 and -2.5 JND. This interval was chosen to define the high to visually lossless quality range. Notably, Testolina et al.[10] report that images in the range between 0 and -1 JND values correspond to the nearly visually lossless range, where artifacts are visible by less than 50% of the population. Images in the range between -1 and -2 JND values correspond to the range from high to nearly visually lossless, where defects are discernible while still maintaining a high *visual appeal*.

Images in the defined quality range, for the JPEG 1, JPEG 2000, HEVC Intra, VVC Intra, and JPEG XL were selected through a subjective visual quality assessment experiment. Nevertheless, as the images compressed with AVIF were added to the dataset at a stage subsequent to the subjective viewing, a different approach was used for the selection of their quality levels, namely using objective image quality metrics. The adopted procedure is the following:

- Two objective metrics, i.e. PSNR and SSIM,[4] were computed on the images selected through subjective viewing. The average metric values over the different codecs were then computed for each image and for each of the 10 selected quality levels.
- The closest metric value between the AVIF-encoded images and the average computed as above was found.

*The JPEG AIC-3 dataset is publicly available at https://www.epfl.ch/labs/mmspg/downloads/jpeg-aic3-dataset/.

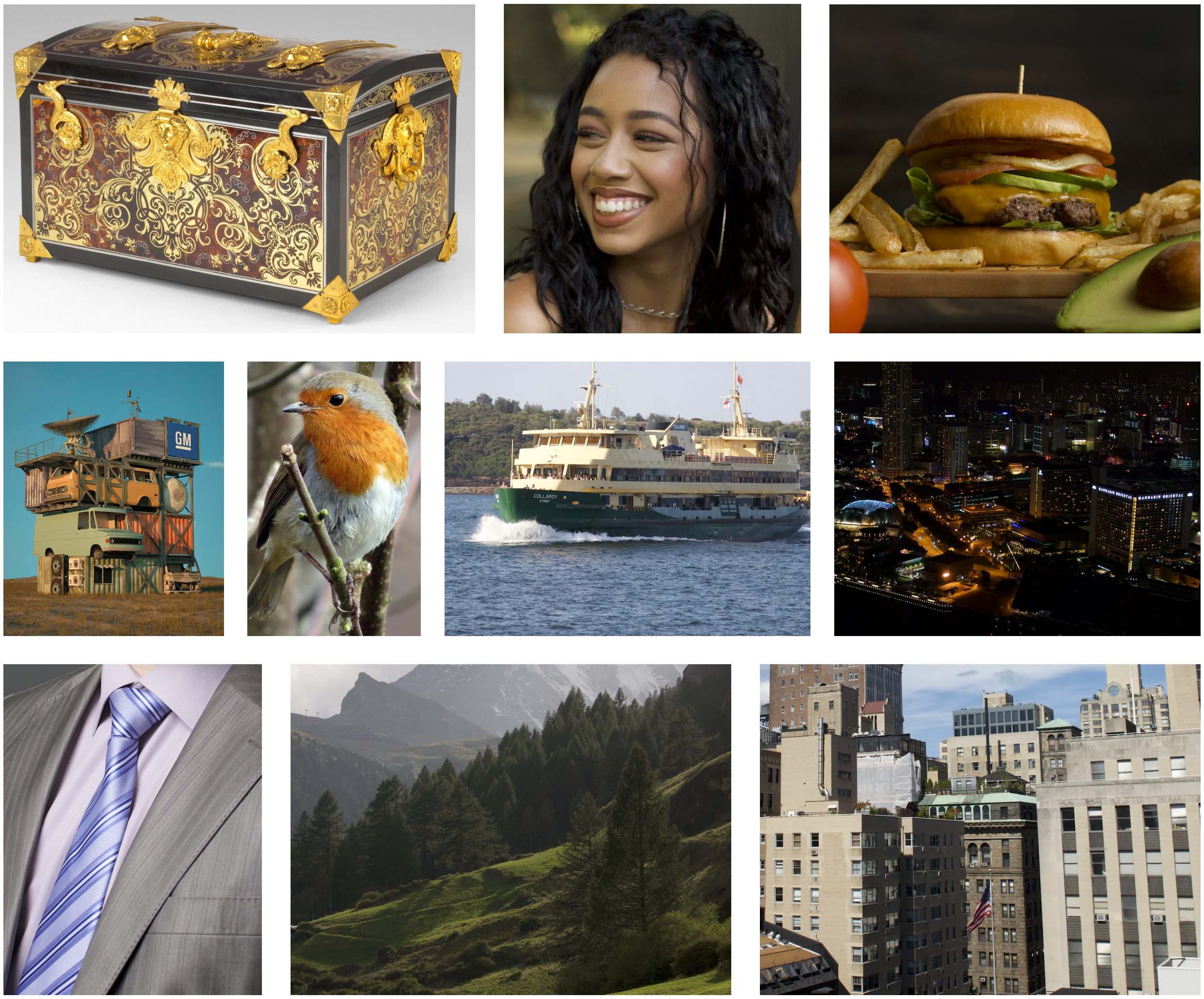


Figure 2: Images part of the JPEG AIC-3 dataset

- Informal subjective viewing was performed by several JPEG experts to validate the selection. Based on their assessment, the final set of images was obtained.

A similar procedure was also applied to image *00004* in the dataset, i.e. for the computer-generated scene, compressed with HEVC Intra and VVC Intra by enabling the screen content coding tool.

An exploration study was conducted in the context of the JPEG AIC-3 activity, targeting a thorough evaluation of well-known subjective image quality assessment methodologies. Notably, subjective visual quality scores were collected on the JPEG AIC-3 dataset using the following three protocols:

- Double Stimulus Continuous Quality Scale (DSCQS):[1] in this methodology, two stimuli, namely a reference and a distorted image, are presented to test subjects side-by-side. The side where the original stimulus is displayed is random and unknown to test subjects. Each test subject is asked to rate the visual quality of both images using a continuous quality scale, presenting labels *Excellent*, *Good*, *Fair*, *Poor*, and *Bad*.

- JPEG AIC-2 Annex A, or AIC-2 A:[3] in this methodology, three stimuli are presented side-by-side to the test subjects. The central stimulus always corresponds to the original uncompressed image, while the images on the sides show the distorted and a copy of the original image. The test subjects are asked to

IMAGE NUMBER	CONTENT	RESOLUTION
00001	Object	1192 × 832
00002	Human portrait	853 × 945
00003	Food	945 × 840
00004	Computer generated	2000 × 2496
00005	Animal	560 × 888
00006	Scene with water	2048 × 1536
00007	Night scene	1600 × 1200
00008	Fabric	1430 × 1834
00009	Landscape	2048 × 1536
00010	Buildings	2592 × 1946

Table 2: Reference images in the JPEG AIC-3 dataset.

choose the closest image to the original (central) between the two alternatives on its sides. Test subjects are able to correctly identify the original image among the two alternatives only if the distortions in the compressed images are visible, or alternatively they submit a random answer.

- JPEG AIC-2 Annex B, or Flicker test:[3] in this methodology, two stimuli are presented to the test subjects side-by-side. One of them corresponds to the original image temporally interleaved with itself, therefore appearing as a static image. The second stimulus is the compressed image temporally interleaved with its original, appearing *flickering* in the case in which the distortions are discernible. Test subjects are asked to select the non-flickering stimulus in a forced-choice paradigm.

The results of the exploration study on JPEG AIC-3 are extensively described in Testolina et al.[12] Subjective visual quality scores were collected using the three different subjective visual quality assessment protocols in three different institutions, namely EPFL, IST, and UBI. At EPFL and IST the order in which the three experiments were performed was the same and corresponds to (1) DSCQS (2) AIC-2 A (3) Flicker test, while at UBI the order was varied as (1) AIC-2 A (2) Flicker test (3) DSCQS. Such difference was introduced to assess if the experience of test subjects influence the results. In order to limit the duration and cost of the experiment, only a subset of the JPEG AIC-3 dataset was used, i.e. only images *00002*, *00004*, *00005*, *00006* and *00007* cropped to a size of 620 × 800, and only JPEG 1, JPEG 2000, VVC Intra, JPEG XL, and AVIF were reviewed. Moreover, for DSCQS and AIC-2 A experiments, only quality levels 2, 5, 8, and 10 were considered, corresponding to JND values of -0.5, -1.25, -2, and -2.5 computed in a subjective pairwise experiment as in Testolina at al.[10] The analysis conducted in the paper reveals different disadvantages for all of the evaluated subjective visual quality assessment methodologies: *i)* the results of the DSCQS experiment were highly influenced by the quality of the original images and by the experience of the test subjects, *ii)* the AIC-2 A methodology was not able to discriminate between images with visual quality lower than visually lossless, *iii)* and finally the Flicker test was not able to provide any relevant result in the quality of range from high to nearly visually lossless.

The analysis conducted by Testolina et al.[12] focuses on the assessment of the different subjective methodologies and lacks an analysis of the performance of the different image compression methods. The subjective visual quality scores collected with the DSCQS protocol are therefore used in this paper to assess the performance of 5 different image codecs. As the experience of the test subjects was found to have a major influence on the results, the subjective visual quality assessment scores collected at EPFL and IST were merged and processed separately from the scores collected at UBI. Rate-distortion plots for each image in the considered subset of the JPEG AIC-3 dataset are presented in Figure 3 (EPFL and IST scores) and Figure 4 (UBI scores).

Figure 3 indicates that, while the results depend on the image content, VVC Intra presents in general higher performance when compared to other codecs. Following, AVIF and JPEG XL have similar performance in most cases, with AVIF presenting higher performance than JPEG XL for image *00005* and *00007*. Finally, JPEG 2000 and JPEG present the lowest rate-distortion performance, with JPEG 2000 presenting higher performance than JPEG for all the investigated images, except for *00007*. Nevertheless, the confidence intervals overlap in most cases, making the results statistically not-significant.

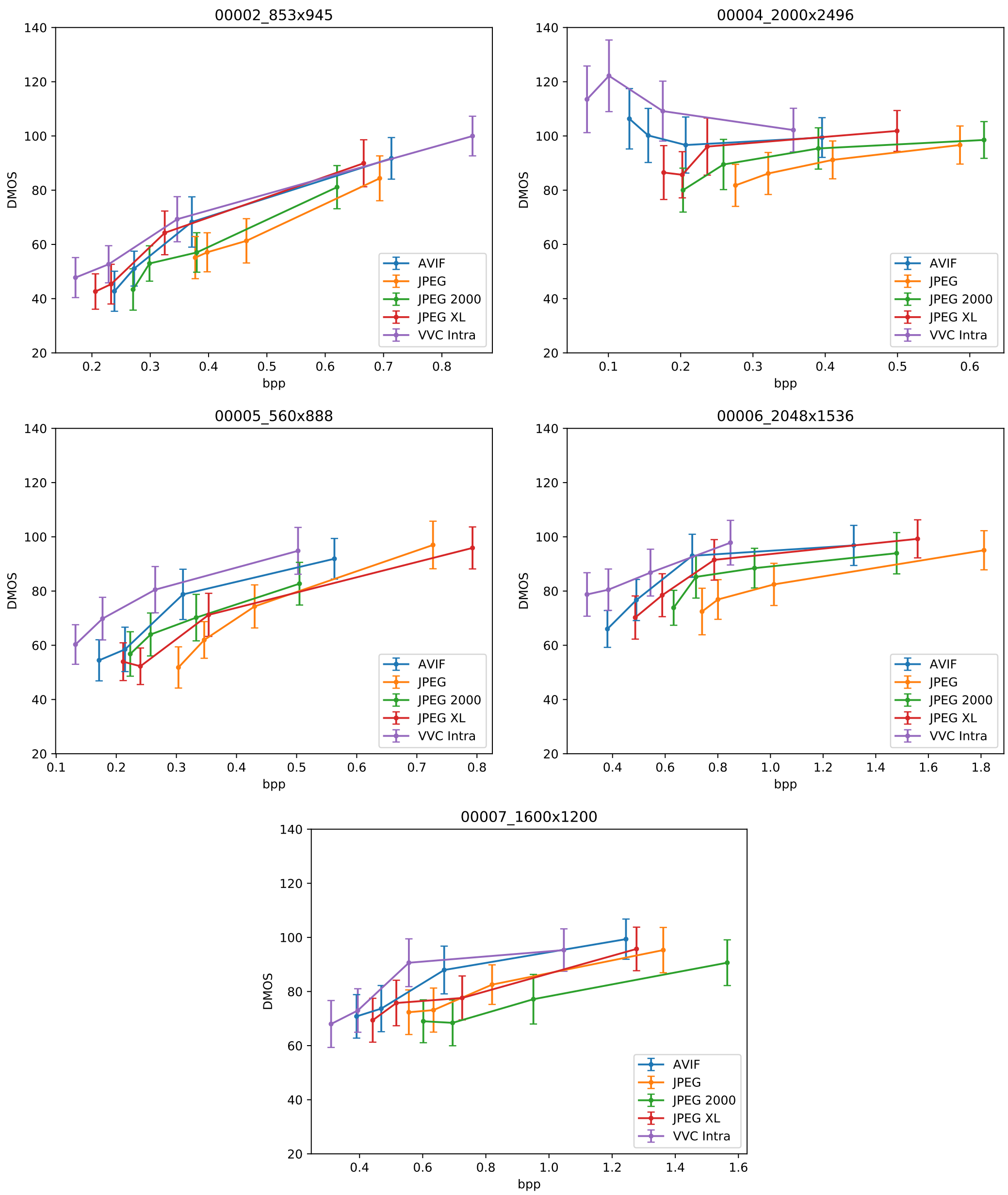


Figure 3: Rate-distortion plots for five images in the JPEG AIC-3 dataset. The subjective scores were collected using the DSCQS protocol as reported in Testolina et al.[12] Only the subjective visual quality scores collected at EPFL and IST are considered and merged together.

A different behavior can be observed in Figure 4, where only the scores collected at UBI are considered, i.e. from test subjects with previous experience with the images and distortion in the dataset. In this case, only the results of 20 test subjects are considered, resulting in higher confidence intervals. Moreover, in most cases, it is impossible to define a best-performing codec. These results support the findings in Testolina et al.,[12] where the DSCQS protocol was found ineffective in providing consistent results while evaluating images with quality in the range from high to nearly visually lossless, particularly when constraints on the cost apply or when subjects have previous experience with the content and distortions in the test dataset, e.g. in the case multiple subjective visual quality assessment experiments are performed to assess different aspects of an image compression method.

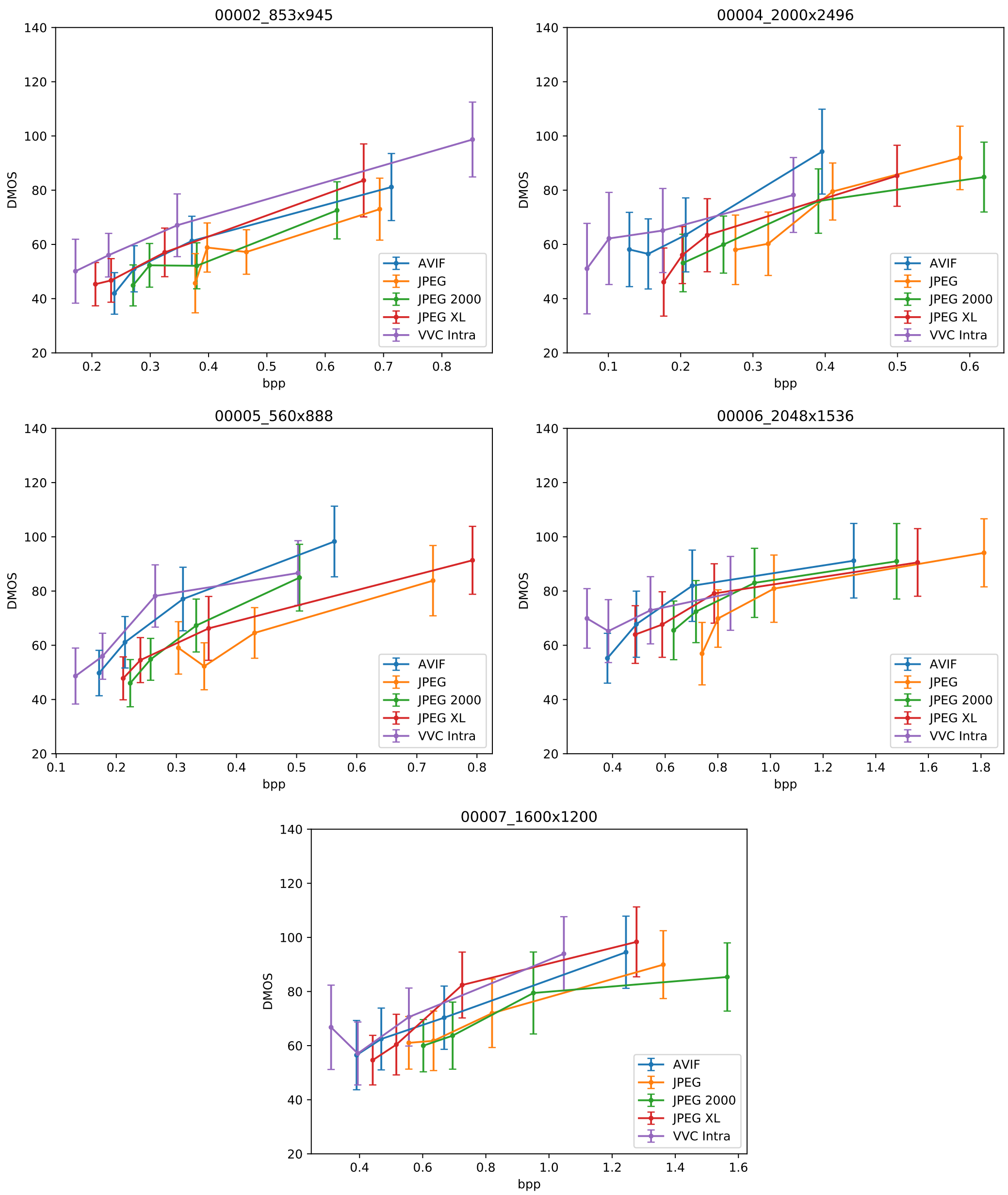
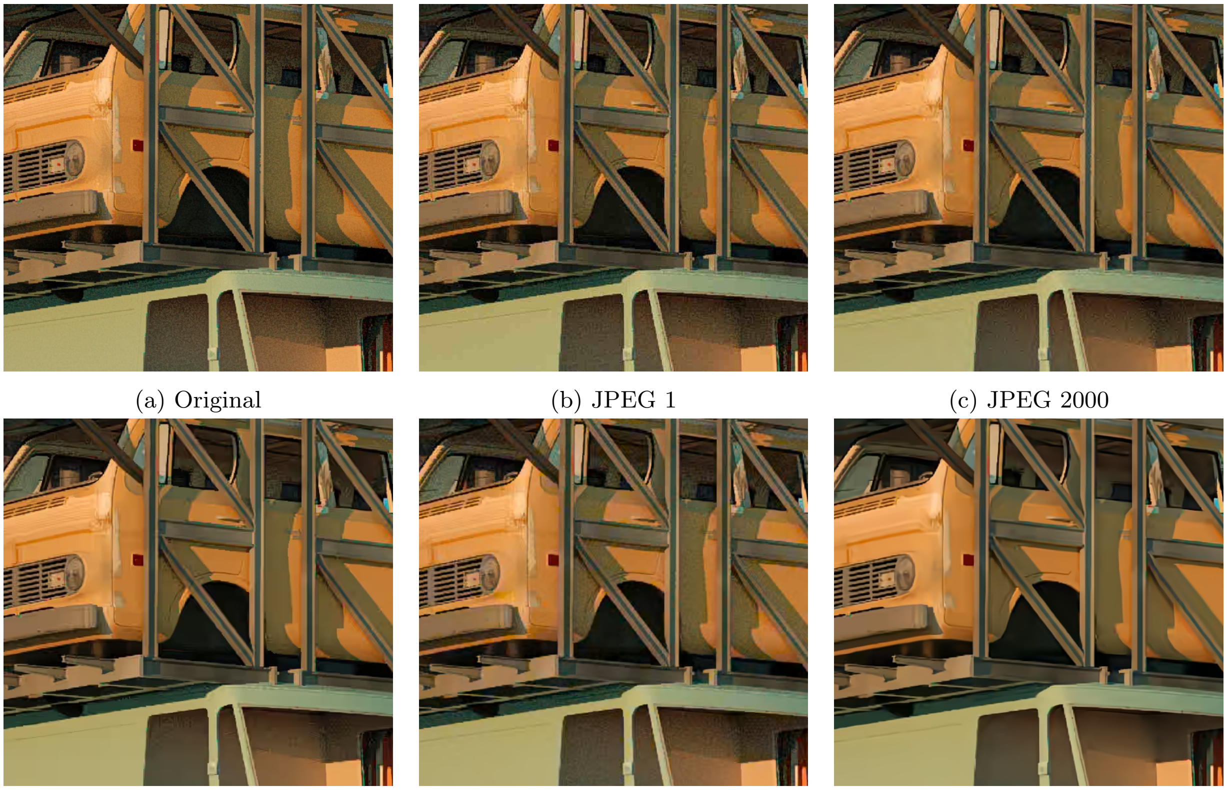


Figure 4: Rate-distortion plots for five images in the JPEG AIC-3 dataset. The subjective scores were collected using the DSCQS protocol as reported in Testolina et al.[12] Only the subjective visual quality scores collected at UBI are considered.

Inconsistencies in the collected subjective visual quality scores can be observed for image *00004*. Notably, Figure 3 shows that images compressed targeting lower bitrates present, in some cases, higher visual quality than the images compressed at higher bitrates. A visual comparison of a crop of image *00004* in its original form and compressed with the codecs analyzed in this paper at the lowest quality level is presented in Figure 5. The figure shows that the original image presents noise, presumably added with artistic intent. Some of the image codecs analyzed in this paper, e.g. AVIF and VVC Intra, introduce blurriness and loss of details as a distortion, which results in denoised-like compressed images. As the DSCQS assesses *visual appeal* of the images, images with such distortion received visual quality scores higher than their reference images, leading to DMOS



(a) Original (b) JPEG 1 (c) JPEG 2000

(d) AVIF (e) JPEG XL (f) VVC Intra

Figure 5: Visual comparison of image *00004* of the JPEG AIC-3 dataset in its original form and compressed with JPEG 1, JPEG 2000, AVIF, JPEG XL and VVC Intra.

values higher than 100. This inconsistency does not occur in Figure 4, as the test subjects were aware that the reference image presented noisy areas and leaned towards assigning lower scores to the compressed denoised-like compressed images. This inconsistency was already highlighted in previous studies.[10,12]

4. CALL FOR CONTRIBUTIONS ON SUBJECTIVE IMAGE QUALITY ASSESSMENT

The analysis conducted in the context of the exploration study on JPEG AIC-3, presented in Testolina et al.,[12] and the analysis conducted in Section 3 revealed that existing standards for subjective image quality assessment present several disadvantages, and highlight the need for new subjective quality assessment methodologies, robust and effective in the range from high to nearly visually lossless.

In this context, a Call for Contributions on Subjective Image Quality Assessment was released, with deadline in April 2023. Three contributions were received:

1. **Boosted Triplet Comparison (BTC)[14]**: a new methodology that specifically targets the range from high to nearly visually lossless. Boosting techniques are applied to the images allowing test subjects to more clearly distinguish minute quality differences, namely by artifact amplification, zooming, and flicker test. The analysis of the submitted results suggests that using boosting techniques leads to better discrimination of artifacts, especially when the artifacts are minute.

2. **CID22[15]**: new methodologies for the evaluation of fidelity of compressed still images were presented in this contribution, combining two different assessment protocols, namely Triple Stimulus Boosted Pairwise

Comparison (TSBPC) and Double Stimulus Boosted Quality Scale (DSBQS). This new methodology was adopted to create the Cloudinary Image Dataset '22 (CID22), a large-scale dataset for medium to visually lossless image compression with a large number of annotations [†]. The analysis of the submitted results suggests that combining relative and absolute data might help assess the visual quality more accurately.

3. **ML-based PC Sampling**[16]: presents a new methodology for pairwise sampling, based on machine learning. Moreover, an evaluation procedure and a benchmarking of state-of-the-art methods are assessed.

5. FUTURE DIRECTIONS: CALL FOR PROPOSALS ON OBJECTIVE IMAGE QUALITY ASSESSMENT

The second step of the renewed JPEG AIC activity will be focusing on objective visual quality metrics efficient in the range from high to nearly visually lossless qualities. For that purpose, a Call for Proposals will be issued. The work will start with a competitive evaluation of proposals against each other in a blind manner that should result in a selection of one or multiple proposals to be used for creating an initial verification model. A collaborative phase will then follow where participants will make contributions to the model through consensus. The subjective visual quality assessment data produced as a result of the first step of the JPEG AIC activity will be used as the ground truth for developing objective metrics.

The JPEG AIC *ad hoc* group has already developed the requirements for objective image quality assessment. These requirements will be used, *inter alia*, for evaluation of the contributions to the Call for Proposals.

Objective Quality Assessment Requirements:

1. **Correlation with subjective scores:** The metrics shall correlate well with subjective scores;
2. **Full-Reference evaluation:** The metrics shall assess the perceptual visual quality of an image under test by comparing it to an original undistorted image;
3. **Variety of image content:** The standard shall be reliable when applied to a variety of image content, i.e. not only photographic images but also synthetic images (graphics, screenshots, etc.);
4. **Computational complexity:** The standard shall define objective quality assessment metrics with reasonable computational complexity and memory consumption, allowing implementation on multiple platforms (in software and hardware).
5. **No-Reference evaluation:** The metrics should assess the perceptual visual quality of an image under test without a need to compare it to an original undistorted image;
6. **Reduced-Reference evaluation:** The metrics should assess the perceptual visual quality of an image under test without a need to explicitly compare it to an original undistorted image, but by using reduced side information about the original undistorted image;
7. **Suitability for wide-gamut and high-dynamic-range images:** The standard should be applicable to wide-gamut and high-dynamic-range images;
8. **Suitability for images with an alpha-transparency component:** The standard should be applicable to images that contain an alpha-transparency component;
9. **Suitability for integration in an image coding pipeline:** The standard shall define objective quality assessment metrics with computational complexity and memory consumption allowing implementation in an image coding pipeline.

In addition, the upcoming JPEG AIC standard will ensure that the data formats for representing subjective visual assessment results are common and allow machine readability by using a syntax that is easy to parse by existing tools.

Interchange Format for Objective and Subjective Scores Requirements:

[†] Available at https://cloudinary.com/labs/cid22. (Accessed in August 2023)

1. **File format specification:** The standard shall specify a format for objective and subjective scores allowing interchange for independent analysis by different parties;
2. **Machine readability:** The format shall use a syntax that is easy to parse by existing tools.

6. CONCLUSIONS

This paper summarized and reviewed current and future activities of the JPEG AIC standardization project. A Call for Contributions on Subjective Image Quality Assessment was released, where three contributions were received, and the collaborative process was initiated during the 99^{th} JPEG meeting, in April 2023. During the 101^{st} JPEG meeting in October 2023, the JPEG Committee is planning to initiate the work on the Objective Image Quality Metrics by drafting a Call for Proposals.

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APPENDIX A. IMAGE CODING INFORMATION

The following naming convention applies:

1. [INPUT]: filename of the original uncompressed image
2. [ENCODED]: filename of the encoded image
3. [DECODED]: filename of the decoded image

A.1 JPEG

```
jpeg -h -qt 3 -s 1x1,2x2,2x2 -q [QUALITY_PARAMETER] [INPUT].ppm [ENCODED].bit

jpeg [ENCODED].bit [DECODED].ppm
```

A.2 JPEG 2000

```
kdu_compress -i [INPUT].ppm -o [ENCODED].bit Qfactor=[QUALITY_PARAMETER] -no_weights -tolerance 0 -full
     -precise -num_threads 1

kdu_expand -i [ENCODED].bit -o [DECODED].ppm -precise -num_threads 1
```

A.3 HEVC

```
TAppEncoderStatic -c encoder_intra_main_scc.cfg -i [INPUT].yuv -wdt [INPUT_WIDTH] -hgt [INPUT_HEIGHT] -
    b [ENCODED].bit -f 1 -fr 25 -q [QUALITY_PARAMETER] --FrameSkip=0 --InputBitDepth=10 --
    InputChromaFormat=444 --ChromaFormatIDC=444 --Level=6.2 --ConformanceWindowMode=1

TAppDecoderStatic -d 10 -b [ENCODED].bit -o [DECODED].yuv
```

A.4 VVC

```
EncoderAppStatic -c encoder_intra_vtm.cfg -i [INPUT].yuv -wdt [INPUT_WIDTH] -hgt [INPUT_HEIGHT] -b [
    ENCODED].bit -f 1 -fr 10 -q [QUALITY_PARAMETER] --InputBitDepth=10 --InputChromaFormat=444 --
    ChromaFormatIDC=444 --TemporalSubsampleRatio=1 --Level=6.2 --ConformanceMode=1

DecoderAppStatic -d 10 -b [ENCODED].bit -o [DECODED].yuv
```

A.5 JPEG XL

```
cjxl [INPUT].png -q [QUALITY_PARAMETER] [ENCODED].jxl

djxl [ENCODED].jxl [DECODED].png
```

A.6 AVIF

```
avifenc -c aom -y 444 --min 0 --max 63 -s 6 -j 1 -a end-usage=q -a tune=ssim -a cq- level=[
    QUALITY_PARAMETER] [INPUT].png [ENCODED].avif

avifdec [ENCODED].avif [DECODED].png
```