JPEG White Paper:

JPEG XL Image Coding System

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Executive Summary

JPEG XL is a new image coding standard targeting capture, storage, archival, transmission, and distribution of photographic images as well as graphics, illustrations, mixed contents (e.g. screenshots) and animations. JPEG XL fills the specific needs for responsive web, wide colour gamut, and high dynamic range applications. It provides legacy transition features, and effective compression at high visual quality. This document provides an overview of the JPEG XL architecture, coding tools and features.

Introduction

The JPEG XL Image Coding System (ISO/IEC 18181) has a rich set of features when compared to commonly used codecs. It is particularly optimised for responsive web environments, so that content renders well on a wide range of devices. Moreover, it includes several features that help transition from the legacy JPEG coding format. Existing JPEG files can be losslessly transcoded to JPEG XL files, significantly reducing their size (Fig. 1). These can be restored into the exact same JPEG file, ensuring backward compatibility with existing JPEG-based applications. Both the transcoding and restoration are computationally efficient. Migrating to JPEG XL reduces storage costs because servers can store a single JPEG XL file to serve both JPEG and JPEG XL clients. This provides a smooth transition path from legacy JPEG platforms to the modern JPEG XL, as illustrated in Figure 1. In this way, JPEG XL can help to reduce server costs (storage size) and network bandwidth (transfer size).

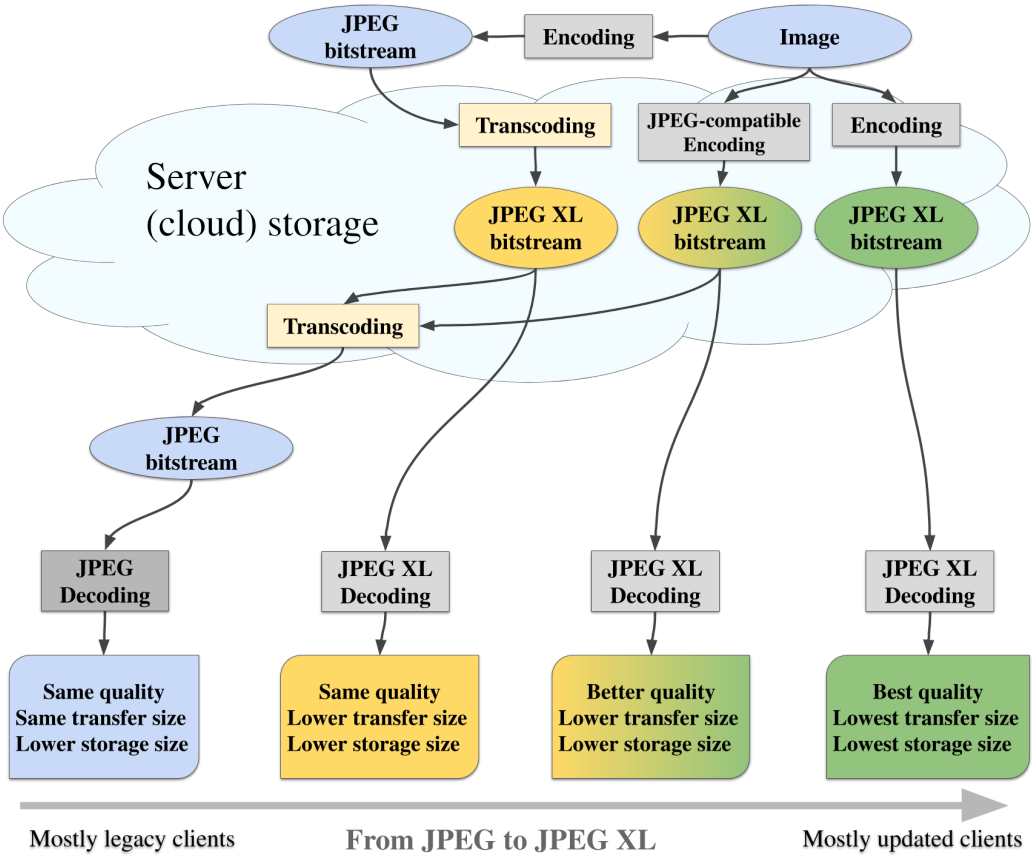

Fig. 1: Example usage scenario

JPEG XL is designed to meet the needs of image delivery on the **web**, as well as professional photography. It supports wide colour gamut as well as high dynamic range and high bit depth images. JPEG XL further includes features such as animation, alpha channels, layers, thumbnails, lossless and progressive coding to support a wide range of use cases[1] including but not limited to photo galleries, e-commerce, social media, user interfaces and cloud storage. To enable novel applications, it also adds support for 360 degree images, image bursts, large panoramas/mosaics, and printing.

JPEG XL offers significantly better image quality and compression ratios compared to legacy JPEG. Considering contemporary alternatives, JPEG XL has a shorter specification and allows a simpler implementation. It is designed for computationally efficient encoding and decoding using software implementations without the need for additional hardware acceleration, even on mobile devices.

Key Features

The complete JPEG XL reference software is available under a **free and open source, royalty-free** license. The contributors have also declared to ISO/IEC that according to the Common Patent Policy they are offering a Type 1 Free of Charge patent grant.

The codec is designed to allow users to balance three primary criteria for their application:

- high fidelity to the source image (closely matching human perception),
- encoding and/or decoding speed,
- compression ratio (typically 20:1 to 50:1).

Key features of the JPEG XL codec are:

1. improved functionality and efficiency compared to traditional image formats (e.g. JPEG, GIF and PNG),
2. progressive decoding (by resolution and precision),
3. lossless JPEG transcoding,
4. support for both photographic and synthetic imagery,
5. graceful quality degradation across a large range of bitrates,
6. perceptually optimized reference encoder,
7. support for wide gamut and HDR,
8. support for animated content,
9. efficient encoding and decoding without requiring specialized hardware.

In the reference software, encoder configuration is done by perceptual target, reliably reaching a desired visual quality, unlike the usual approach of configuring by means of bitrate or quantization settings, which results in a highly image-dependent visual quality.

In terms of compression performance, key results are:

- Lossless JPEG transcoding reduces JPEG size by around **16% to 22%**.
- JPEG XL is visually lossless at about half the bitrate required by JPEG.

[1] ISO/IEC JTC 1/SC 29/WG1, "JPEG XL Use Cases and Requirements" output document wg1n83043, Geneva, Switzerland (March 2019), https://jpeg.org/static/documents/wg1n83043-REQ-JPEG_XL_Use_Cases_and_Requirements.pdf. Accessed: 2020-01-10.

- In side-by-side comparisons, JPEG XL is visually lossless (shaded blue area) typically at similar bitrates as HEVC-HM-Y444. Figure 2 shows results from a subjective evaluation[2].

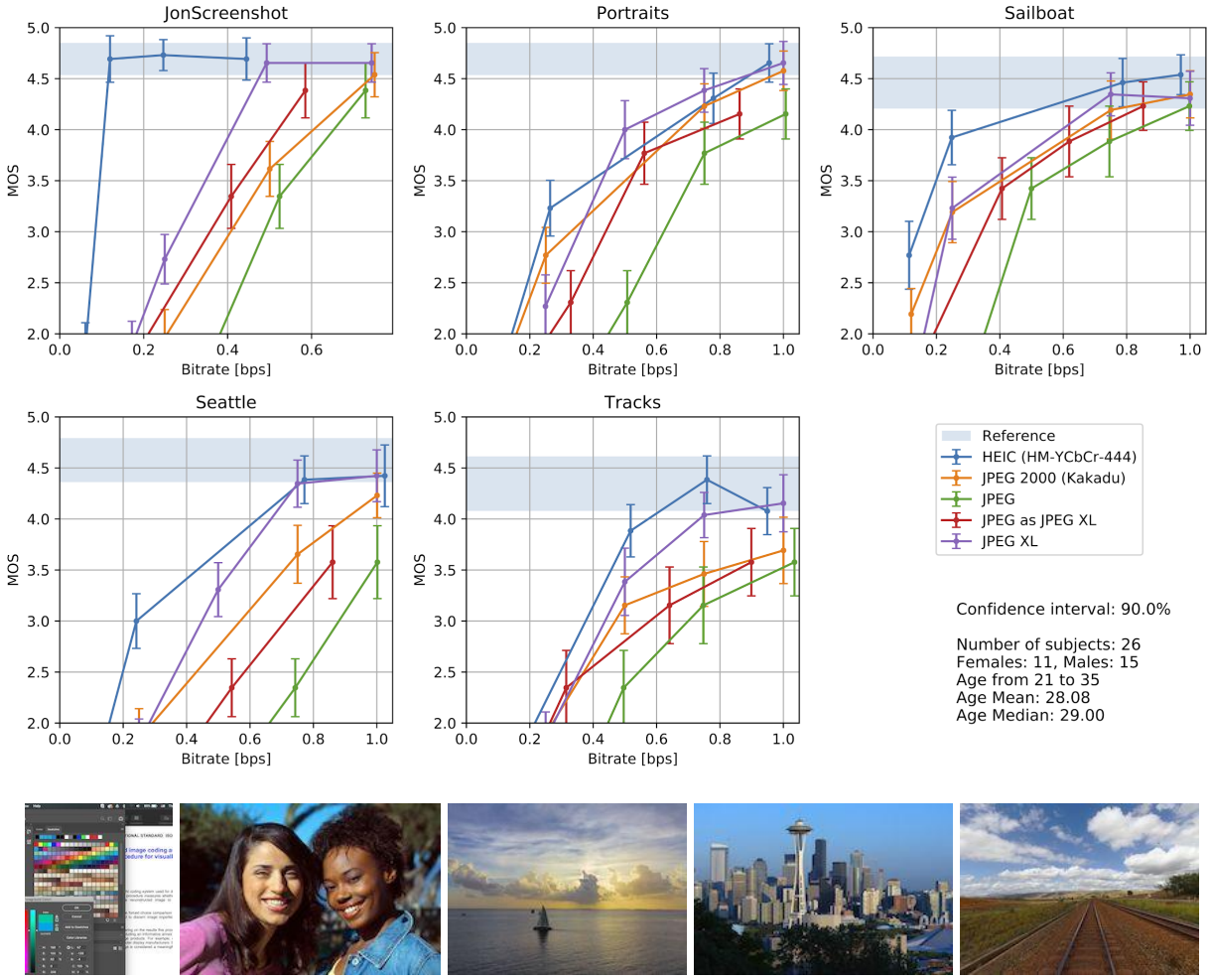

Fig. 2: Examples of subjective evaluation, with mean opinion scores for various bitrates.

Codec Architecture

JPEG XL has two coding modes, shown in the encoder diagram in Figure 3:

- VarDCT (green): lossy encoding of photos with an emphasis on the human visual system; can also be used for lossless transcoding of existing JPEG images,
- Modular (red): mathematically lossless encoding or generic lossy encoding.

VarDCT mode uses Modular mode to store sub-images such as DC (8x8 subsampled), control fields (e.g. for colour correlation and filtering), and extracted image features (“patches”) as explained further below.

For lossless transcoding of JPEG bitstreams (to reconstruct not just the image data, but also the bit-exact file), optional JPEG bitstream reconstruction data can be stored (shown in yellow).

[2] J. Alakuijala et al., "Benchmarking JPEG XL image compression," Proc. SPIE 11353, Optics, Photonics and Digital Technologies for Imaging Applications VI, 113530X (1 April 2020); https://infoscience.epfl.ch/record/277420/files/Submitted%20manuscript.pdf.

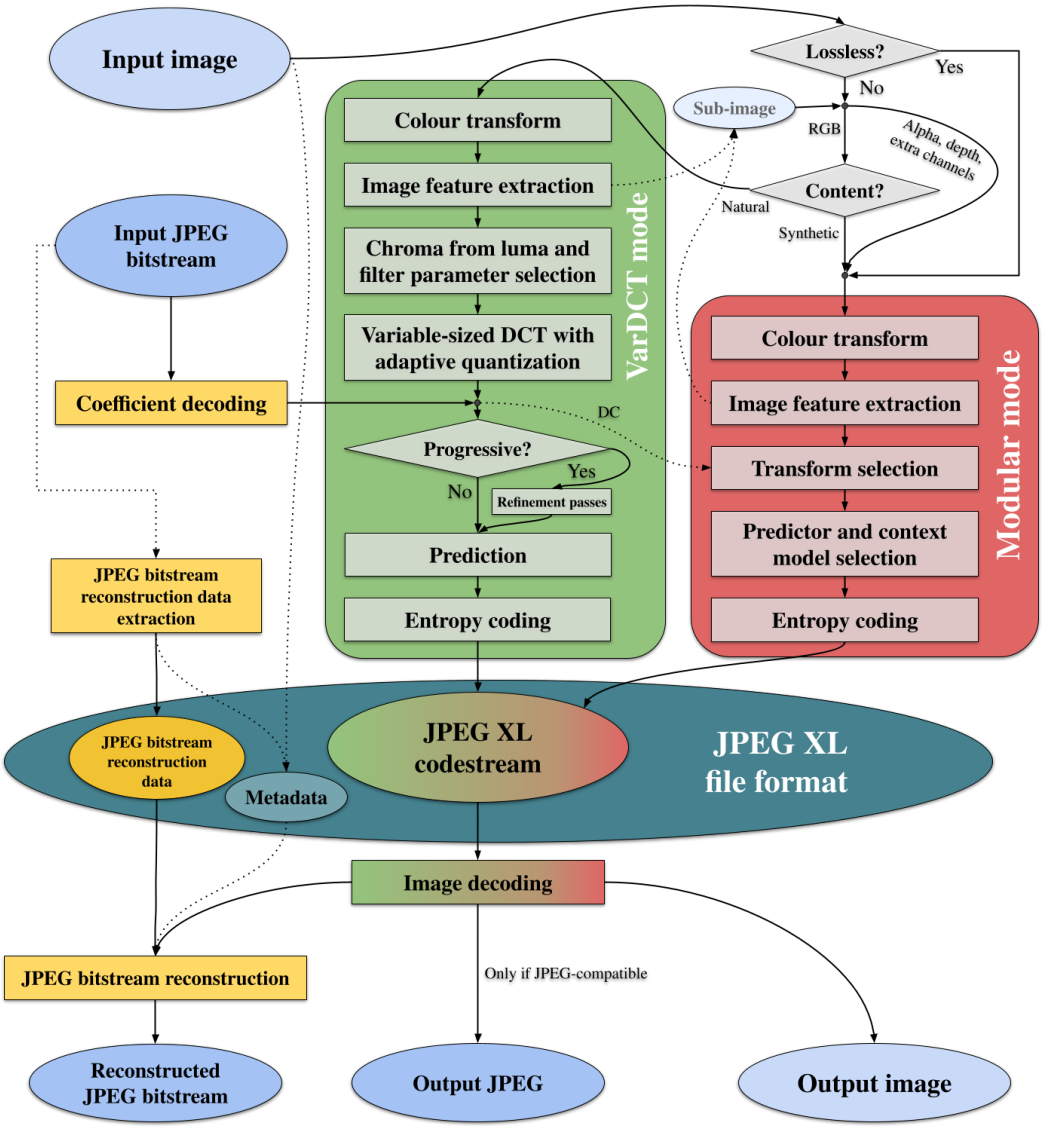

Fig. 3: Overview of the encoder architecture and associated functionalities. An input image can be encoded as a compressed JPEG XL codestream in a lossless or lossy way, and decoded to an identical or perceptually similar output image. An input JPEG bitstream can be encoded as a JPEG XL file, containing a codestream that uses a subset of the VarDCT mode coding tools (to represent the image data) as well as JPEG bitstream reconstruction data, which can be decoded to an identical reconstructed JPEG bitstream.

Coding Tools

A JPEG XL file can contain one or more frames, e.g. for animation or overlays. Frames may be subtracted from prior frames without motion compensation and can have smaller bounding boxes, blend modes and dispose modes. They may also reference regions from prior frames marked as reference frames, which can serve as a simple **inter-frame** coding tool and as a **screen content** coding tool for still images.

Each frame is split into groups for **parallel encoding and decoding** and efficient **region-of-interest** (cropped) decoding. The group size for VarDCT mode is 256x256 pixels (with special border handling), and 128x128 to 1024x1024 in Modular mode. Besides thread-parallelism, the coding tools have also been designed for SIMD (single instruction, multiple data), making the JPEG XL codec suitable for efficient CPU encoding and decoding on current desktop and mobile processors.

Special attention has been devoted to **reducing header and metadata overhead**, including compression of colour profiles and Exif/XMP metadata, which is especially important for web delivery of smaller images.

A brief description of other JPEG XL coding tools follows:

- **XYB colour space** is a colour model inspired by the human visual system, facilitating perceptually uniform quantization. It uses a gamma of 3 for compute-efficient decoding.
- **Image features** are rendered on top of the decoded image, for precise and dense representations of repeated elements ("patches"), curvilinear image features ("splines"), and adaptive, intensity dependent synthetic noise modeling.
- **Chroma from luma** allows local colour decorrelation using signaled multipliers.
- Per-block **restoration filter parameters** help to suppress artifacts while preserving fine detail.
- **Variable-sized DCT** (square or rectangular from 2x2 to 256x256) serves as a fast approximation of the optimal decorrelating transform. DCT coefficients may be sent in arbitrary order.
- **Adaptive quantization** uses per-block quantization step sizes which also guide the restoration filter.
- **Prediction** is run using a pixel-by-pixel decorrelator without side information, including a parametrized self-correcting weighted ensemble of predictors.
- **Context modeling** includes specialized static models and powerful meta-adaptive models that take local error into account, with a signalled tree structure and predictor selection per context.
- **Entropy coding** is LZ77-enabled and can use both Asymmetric Numeral Systems and Huffman (for low complexity encoders or for reducing overhead of short streams); integers of arbitrary length are supported through a configurable splitting mechanism of integers into symbols and raw bits.
- **Transforms** include reversible colour transforms (including a generalized delta palette transform) and a modified nonlinear Haar wavelet, which enables efficient and progressive decoding.
- **Progressive refinement** and responsive features include recursively progressive DC (cf. Figure 4), spectral selection and successive approximation passes for AC, saliency-based passes, and group permutation (e.g. center-to-border instead of scanline order, for example for 360 images).

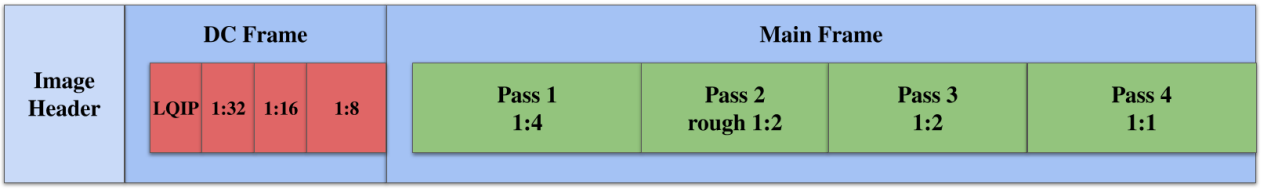

Fig. 4: Example bitstream structure for progressive refinement with multiple passes and DC encoded recursively

Conclusion

JPEG XL achieves efficient and high-quality image compression and responsive delivery. It is designed to be a practical and modern replacement for existing usages of JPEG, PNG and GIF formats. An advanced perceptual model in the encoder enables visually lossless quality at compression ratios of around 20:1.
Open-source reference software is available at http://gitlab.com/wg1/jpeg-xl and additional information is available at https://jpeg.org/jpegxl/.

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