Image Compression Standards II

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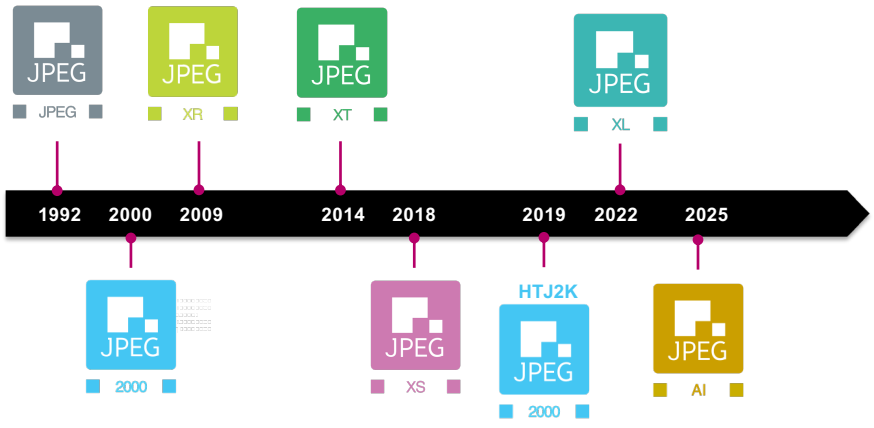
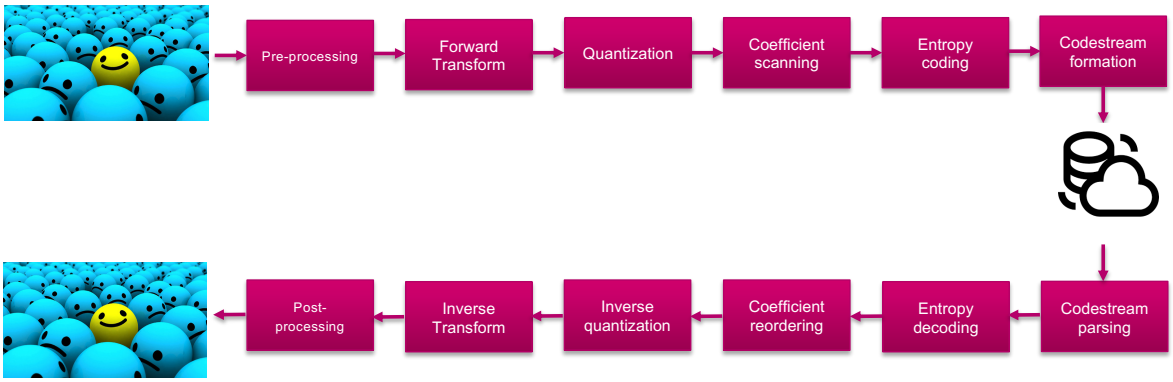
1

A continuously evolving family of standards



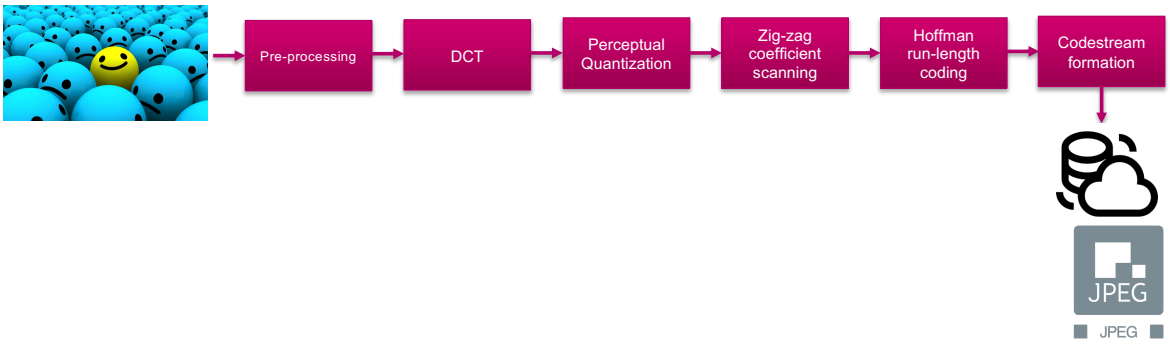
2

Transform based coding



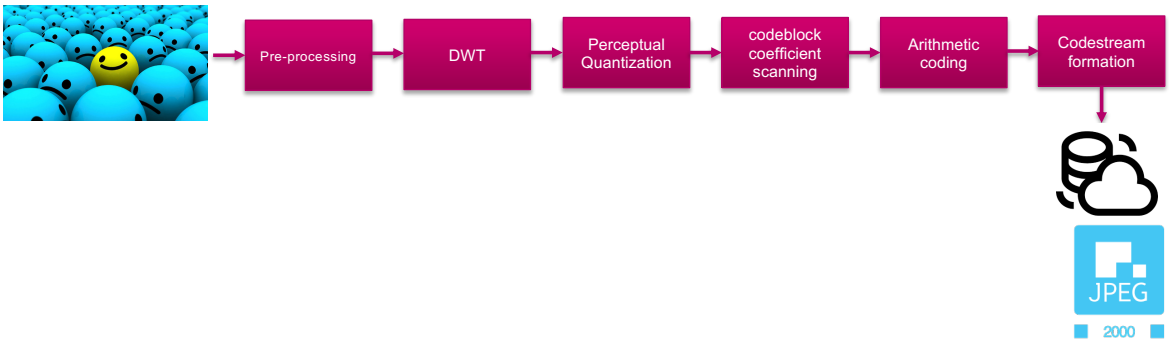
3

Transform based coding in JPEG

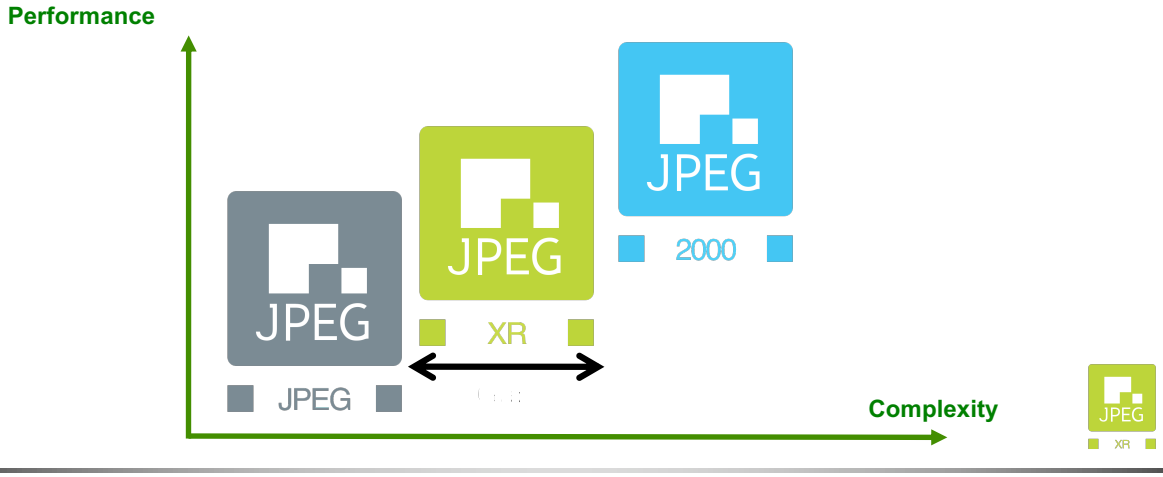


4

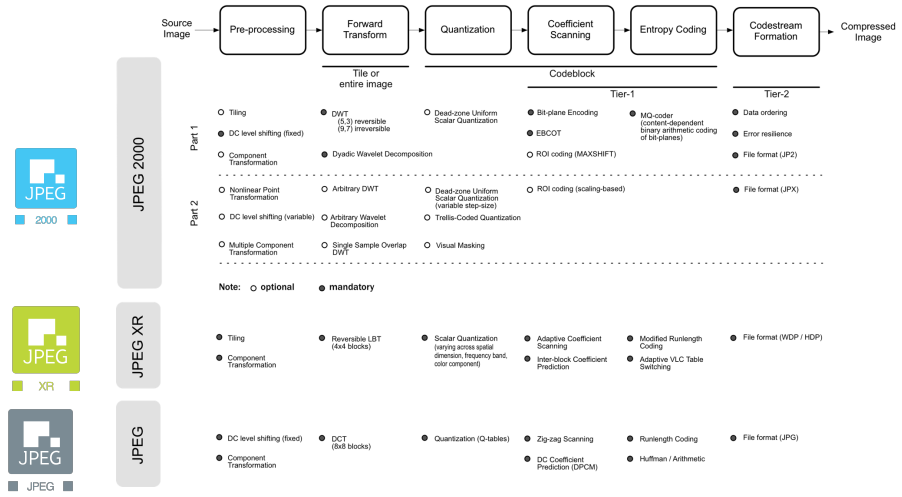
Transform based coding in JPEG 2000



JPEG XR

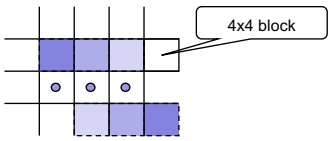


JPEG vs JPEG 2000 vs JPEG XR

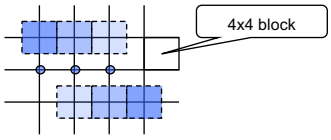


JPEG XR transform

- JPEG XR transform consists of 2 building blocks
  - Core transform (PCT) which is similar to a 4x4 DCT

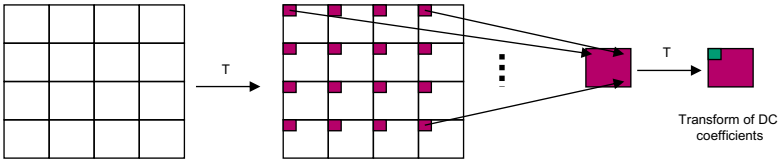


  - Overlap transform (POT) which is shifted to reduce blockiness



JPEG XR transform

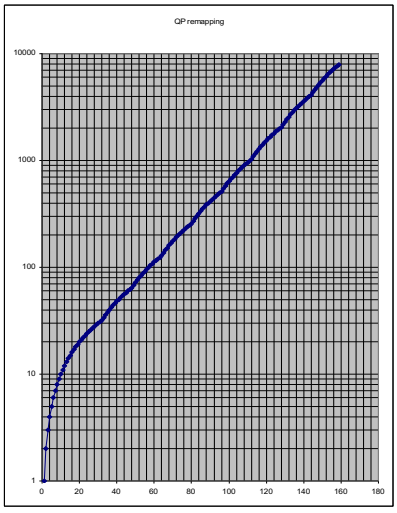
- Hierarchical transform
  - Two transform stages – second stage operates on DC of 4x4 blocks of first stage



- 3 overlap modes supported
  - Mode 0 or no overlap, which reduces to 2 stages of 4x4 core (block) transform
    - *Lowest complexity mode*
  - Mode 1 – overlap operator applied only to full resolution data, and not to second stage
    - *Best R-D performance*
  - Mode 2 – overlap operator applied at both resolutions
    - *Best visual quality at very high compression*

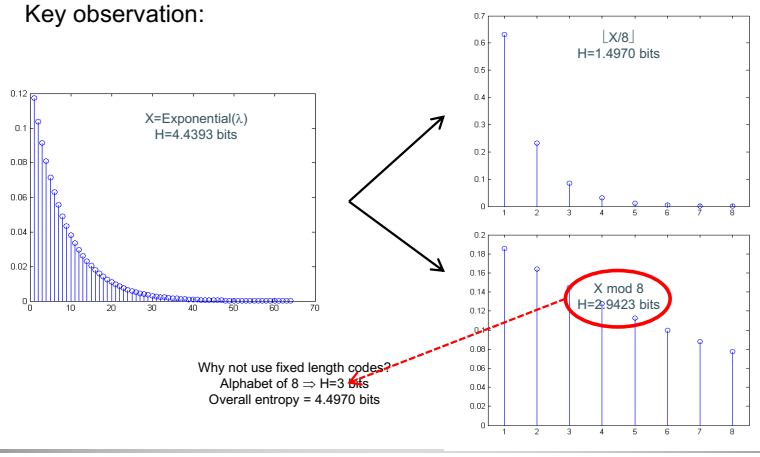
JPEG XR quantization

- "Harmonic" quantization scale
  - Defined by the set
    $\{Q\} \cup \{(Q+16)\,2^k\}$, for $Q = 0 \ldots 15$
- Transform coefficients are equal norm by design
  - No additional scaling required during (de)quantization to compensate for unequal norms



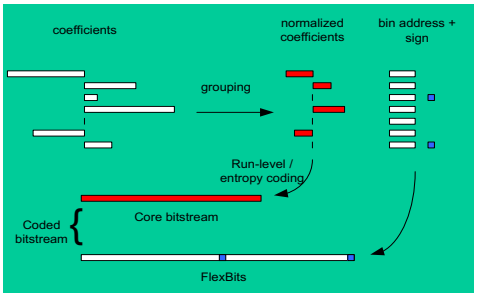
JPEG XR entropy coding

- Adaptive coefficient normalization
  - Handles high-variance transform coefficient data
  - Key observation:



JPEG XR entropy coding

- Adaptive coefficient normalization
  - Triggered when nonzero transform coefficients happen frequently
  - When triggered, additional bit stream layer “Flexbits” is generated
    - *Flexbits is sent “raw”, i.e. uncoded*
    - *For lossless 8 bit compression, Flexbits may account for more than 50% of the total bits*
    - *Flexbits forms an enhancement layer which may be omitted or truncated*



JPEG XR entropy coding

SYMBOL	Code 0	Code 1	Code 2	Code 3	Code 4
0	0000 1	0010	11	001	010
1	00 0001	0 0010	001	11	1
2	000 0000	00 0000	000 0000	000 0000	000 0001
3	000 0001	00 0001	000 0001	0 0001	0001
4	0 0100	0011	0 0001	0 0010	000 0010
5	010	010	010	010	011
6	0 0101	0 0011	000 0010	000 0001	0000 0000
7	1	11	011	011	0010
8	0 0110	011	100	0 0011	000 0011
9	0001	100	101	100	0011
10	0 0111	0 0001	000 0011	00 0001	0000 0001
11	011	101	0001	101	0 0001

SYMBOL	Code 0	Code 1	Code 2	Code 3
0	1	01	0000	0 0000
1	0 0000	0000	0001	0 0001
2	001	10	01	01
3	0 0001	0001	10	1
4	01	11	11	0001
5	0001	001	001	001

All code tables used in JPEG XR for coefficient and coded block pattern coding, enumerated in binary

SYMBOL	Code 0
0	1
1	01
2	001
3	000

SYMBOL	Code 0	Code 1
0	010	1
1	0 0000	001
2	0010	010
3	0 0001	0001
4	0 0010	00 0001
5	1	011
6	011	0 0001
7	0 0011	000 0000
8	0011	000 0001

SYMBOL	Code 0	Code 1
0	01	1
1	10	01
2	11	001
3	001	0001
4	0001	0 0001
5	0 0000	00 0000
6	0 0001	00 0001

SYMBOL	Code 0	Code 1
0	1	1
1	01	000
2	001	001
3	0000	010
4	0001	011

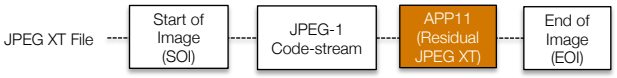
SYMBOL	Code 0
0	10
1	001
2	0 0001
3	0001
4	11
5	010
6	0 0000
7	011

JPEG XT backward compatible compression

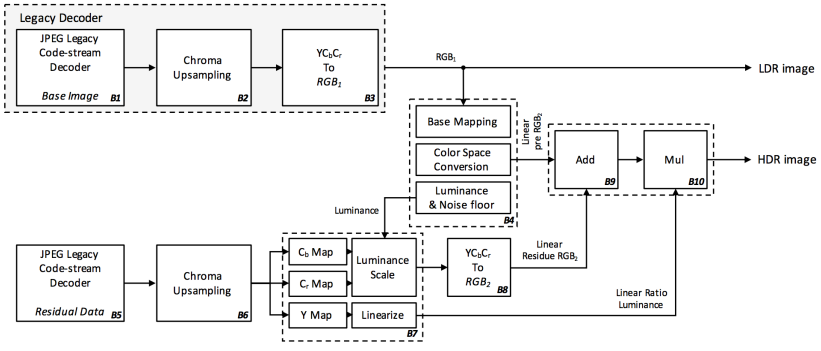
- A JPEG legacy compatible HDR image compression standard

- Exif and JFIF use APP marker of JPEG
  - Reserved for application segments

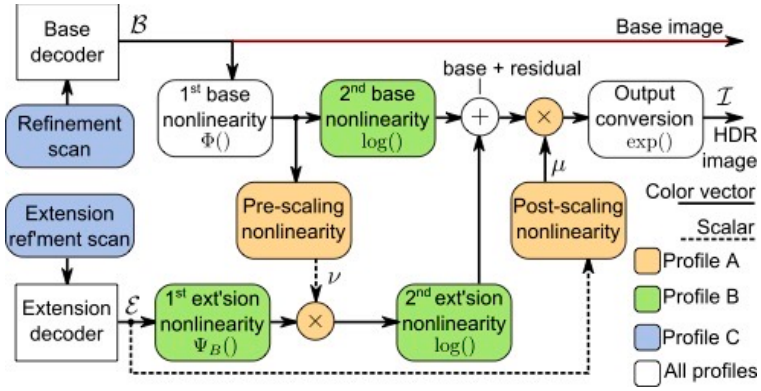
APP marker (0 to 15)	Format
APP0	JFIF, JFXX
APP1	Exif
APP2	ICC Profile
APP3	JPSearch Part2
APP14	Adobe



- Two-layer coding, with **base layer a <u>legacy JPEG coded LDR</u>** and enhancement layer the residual to produce the HDR
- Enhancement layer uses a maximum of JPEG Legacy coding tools



JPEG XT profiles



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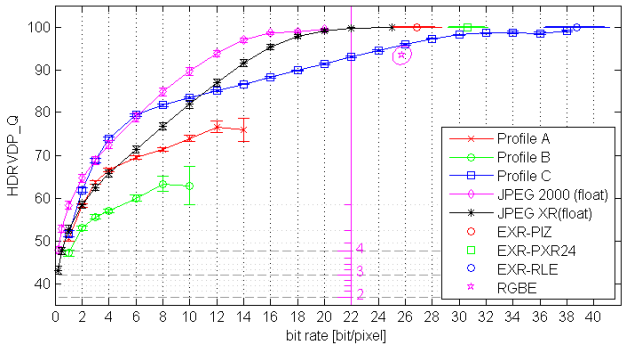
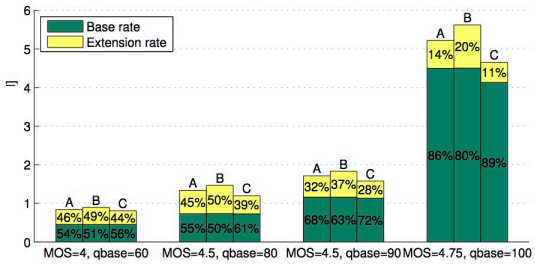
JPEG XT compression efficiency





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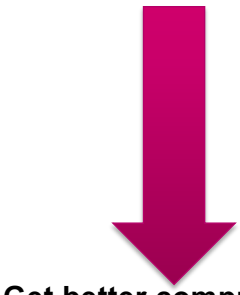
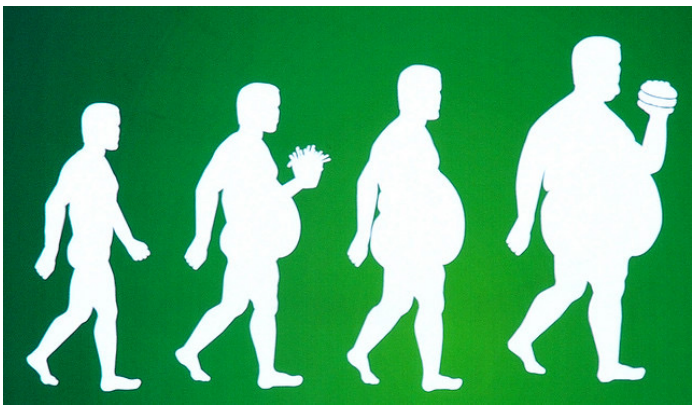
Compression game over the last +40 years

Increase complexity



Get better compression

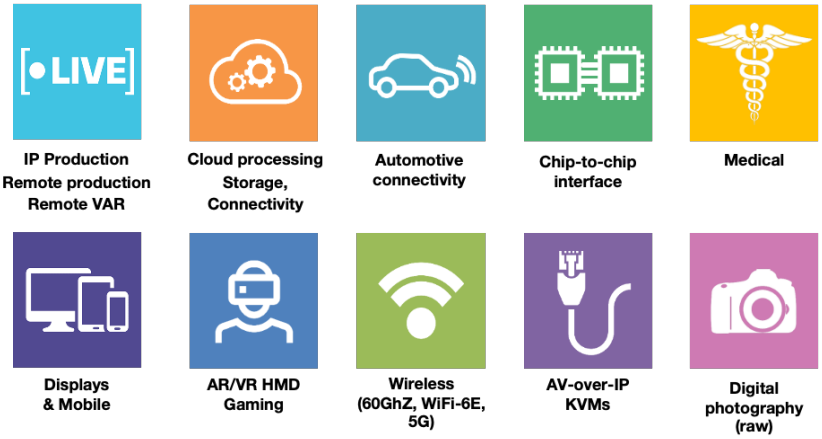


Why do light-weight compression?

Solve bandwidth limitations, without compromising on complexity, latency, or quality.

FORMATS	Uncompressed 4:4:4 10 bit	JPEG XS (TDC)	IP Networks
HD 1080p60 4:4:4	~3.73 Gbps	150 – 400 Mbps	1 to 6 streams / 1GbE
4K 2160p30 4:4:4	~0.9 Gbps	250 – 750 Mbps	1 to 4 streams / 1GbE 3 – 10 streams / 2.5GbE
4K 2160p60 4:4:4	~15.9 Gbps	400 – 750 Mbps	1 to 2 streams / 1GbE 1 – 5 streams / 2.5GbE
8K 4320p30 4:4:4	~28.8 Gbps	0.75 – 2.5 Gbps	1 stream / 1GbE 1 – 2 streams / 2.5GbE
8K 4320p60 4:2:0/4:2:2/4:4:4	~59.71 Gbps	1.5 – 2.5 Gbps	1 stream / 2.5GbE

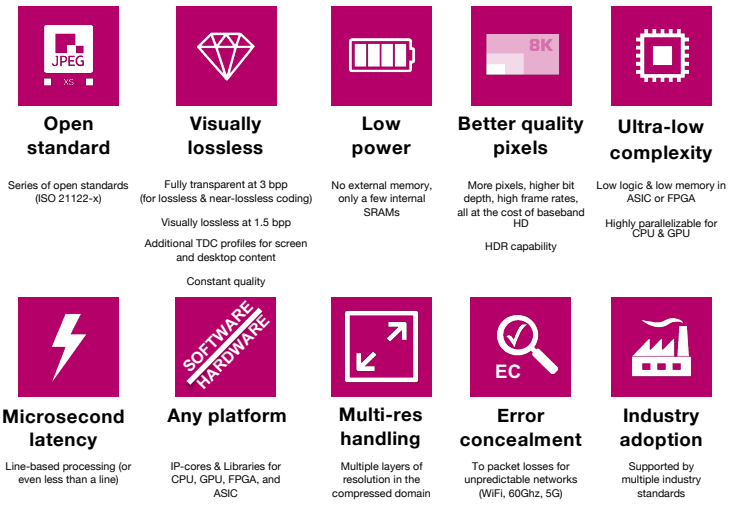
Use cases: when uncompressed data rates are not realistic



EVERYWHERE where uncompressed is the norm

JPEG XS

Key benefits



JPEG XS

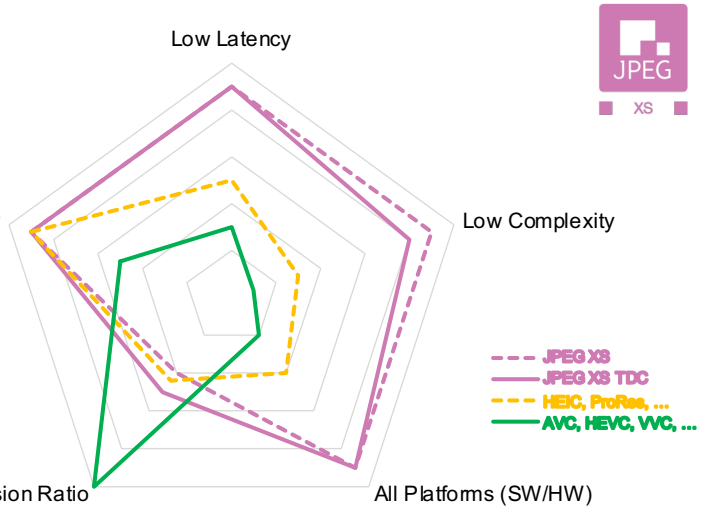
JPEG XS Scope

The scope of JPEG XS is to provide
a low-latency lightweight image coding system,
replacing uncompressed image and video everywhere.

JPEG XS was the first true high-quality codec with REDUCED complexity compared to other coding technologies!

JPEG XS design strategy

- Transparent quality
- Low complexity
- Ultra low latency (~lines)
- Compression efficiency
- Any platform



Multiple degrees of parallelism.

Symmetrical complexity between encoder & decoder.

Best trade-off between the multiple requirements.

Future proof

Multiple resolutions – HD, 4K, 8K… up to 16K or more

Multiple chroma formats – 4:4:4, 4:2:2, 4:2:0, 4:0:0 (grayscale/alpha), 4:2:2:4, 4:4:4:4

Any color space – RGB, YUV, XYZ, CFA RAW Bayer

Multiple bit depths – 8, 10, 12, 14, 16 bits

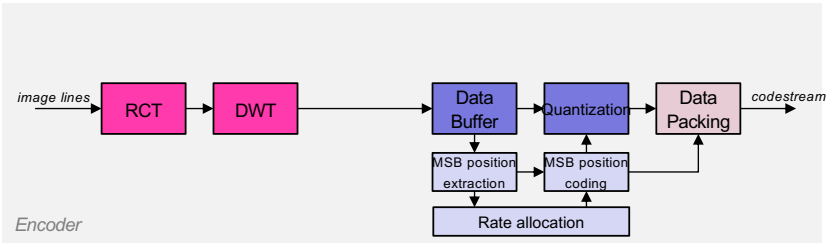
HDR support – All signaling support (SDR, HDR,…)

Any frame rates – No limitations

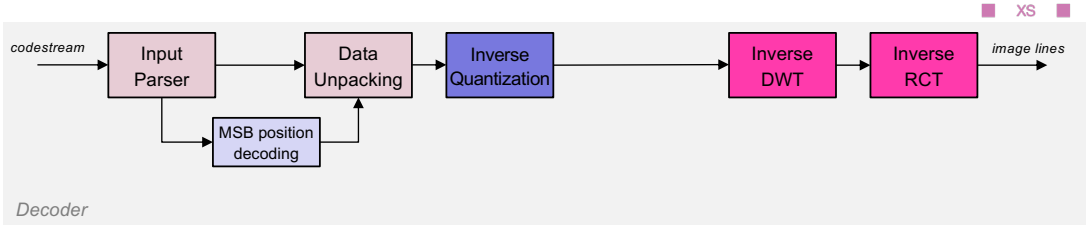
Scalability – Lower resolution proxies are part of the XS master! Can be directly decoded.

Open Specifications – XS is an ISO JPEG standard following RAND policy

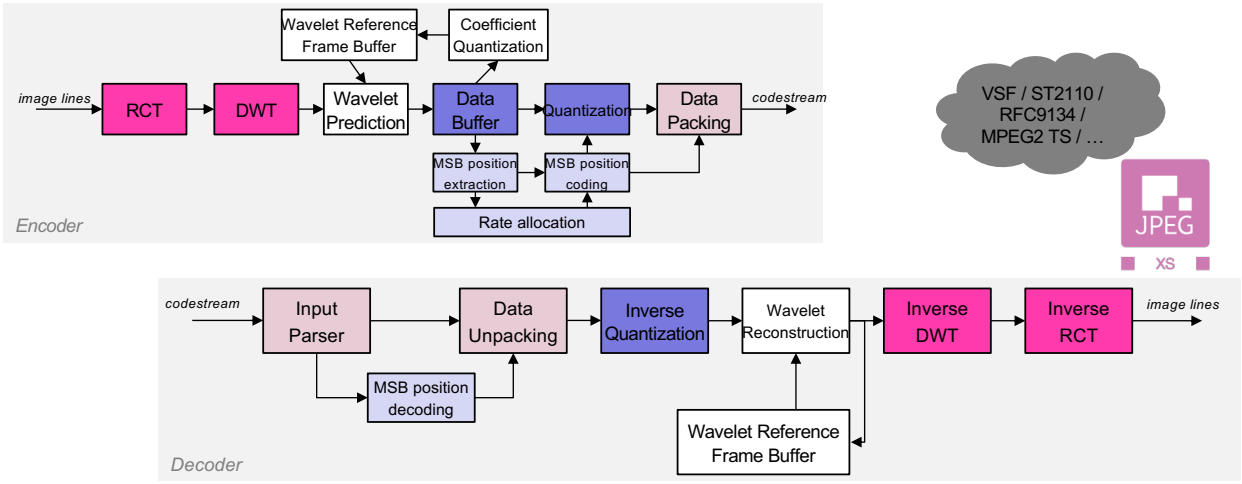
JPEG XS architecture



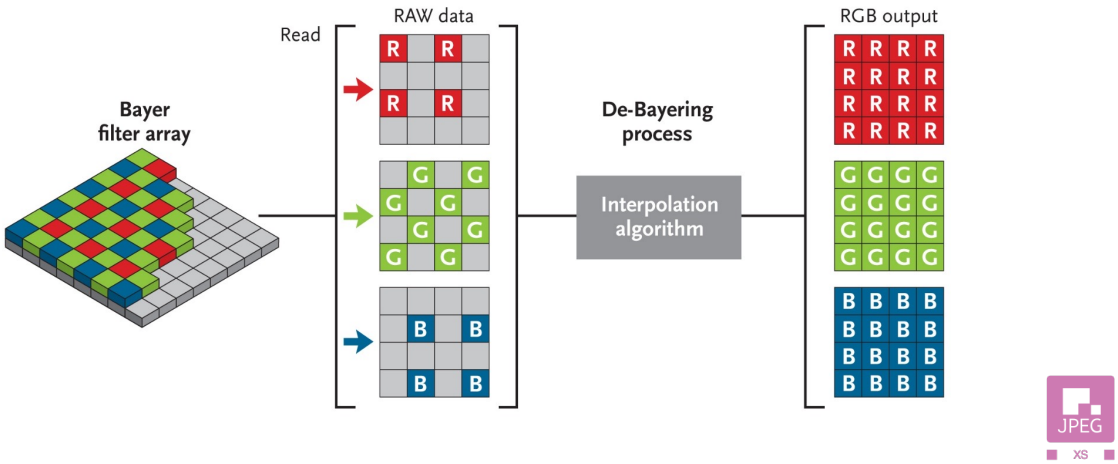
VSF / ST2110 / RFC9134 / MPEG2 TS / …



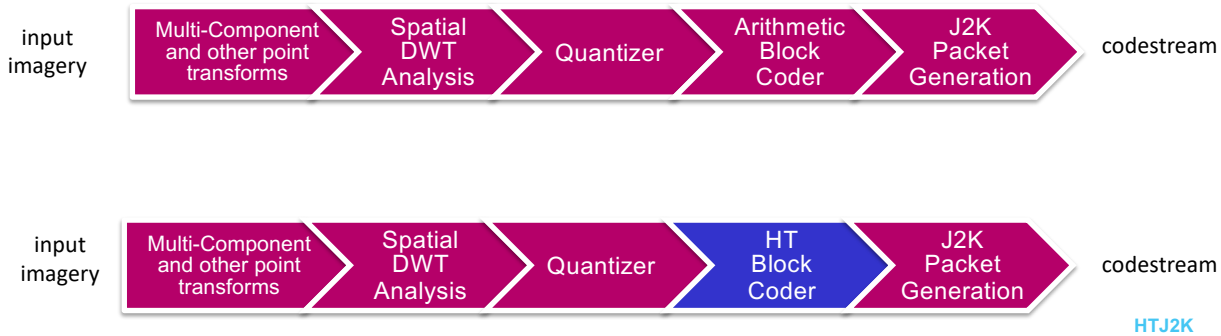
JPEG XS architecture with temporal differential coding (TDC)



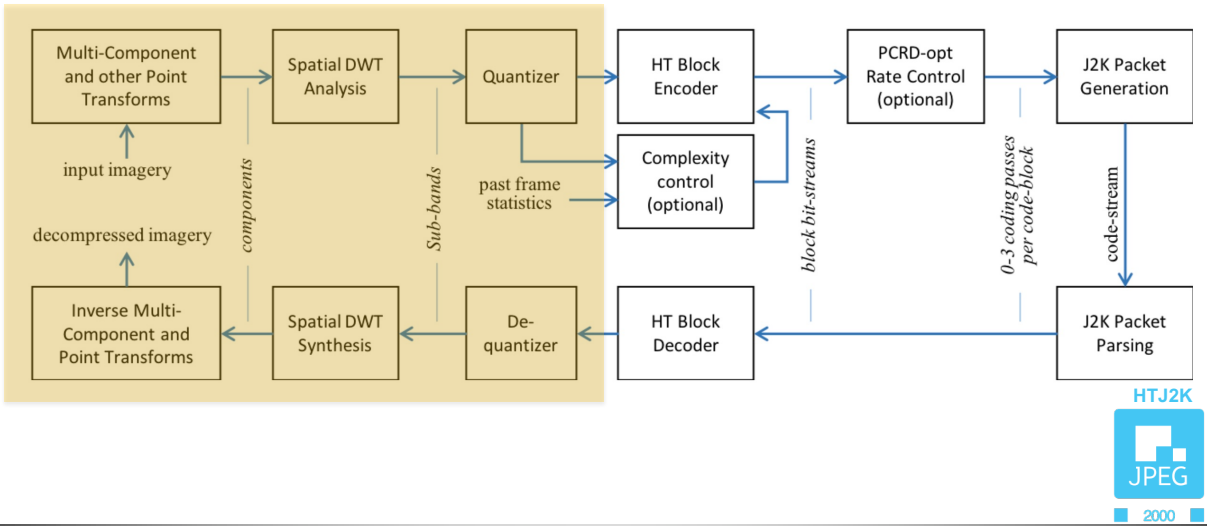
JPEG XS Sensor compression



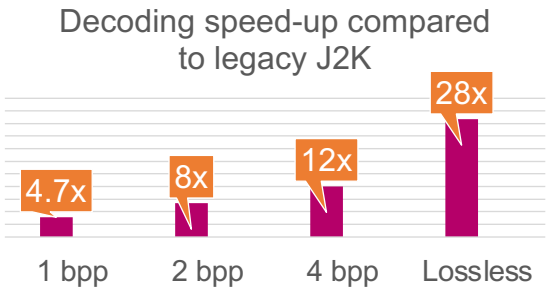
High Throughput JPEG 2000

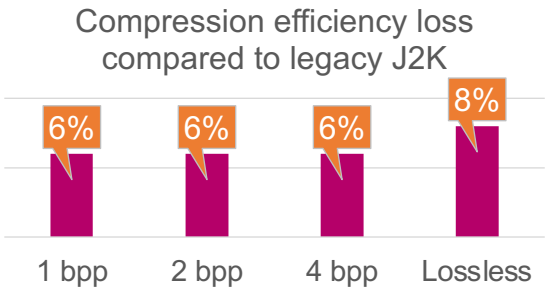


HTJ2K - High Throughput JPEG 2000 (ISO/IEC 15444-15)



HTJ2K – A faster J2K!





Numerically lossless transcoding of HTJ2K to/from legacy JPEG 2000

HTJ2K
JPEG
2000

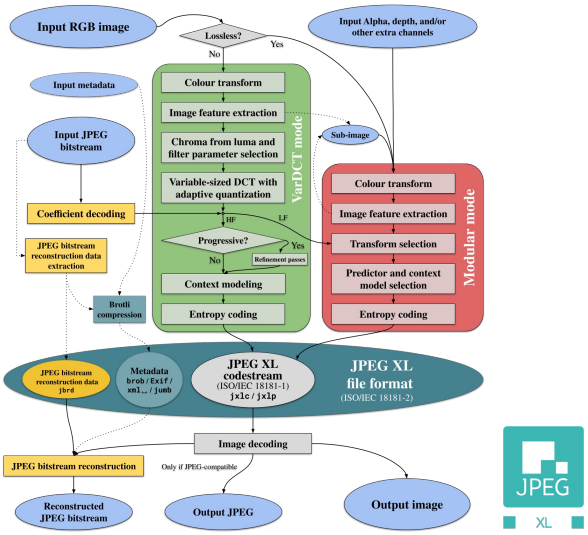
JPEG XL (ISO/IEC 18181)

- detail/texture preservation
- economical storage
- mixed content (photo, synthetic)
- progressive/ responsive (multi-res)
- region decode (+saliency)
- high dynamic range, wide color gamut
- rapid capture mode
- fast software (SIMD, parallel)
- mobile friendly
- short specification
- royalty-free patent grant
- open source (Apache 2)
- animations/ bursts
- layers/ alpha
- 360-degree images
- lossless JPEG transcoding
- enhanced JPEG decoding
- noise synthesis

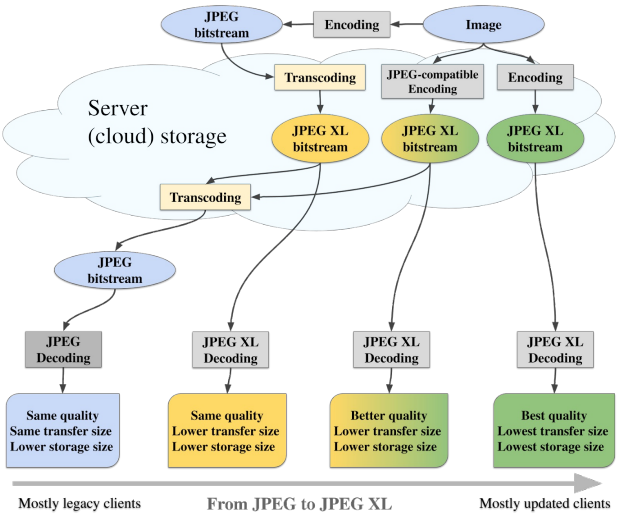
JPEG
XL

JPEG XL coding architecture

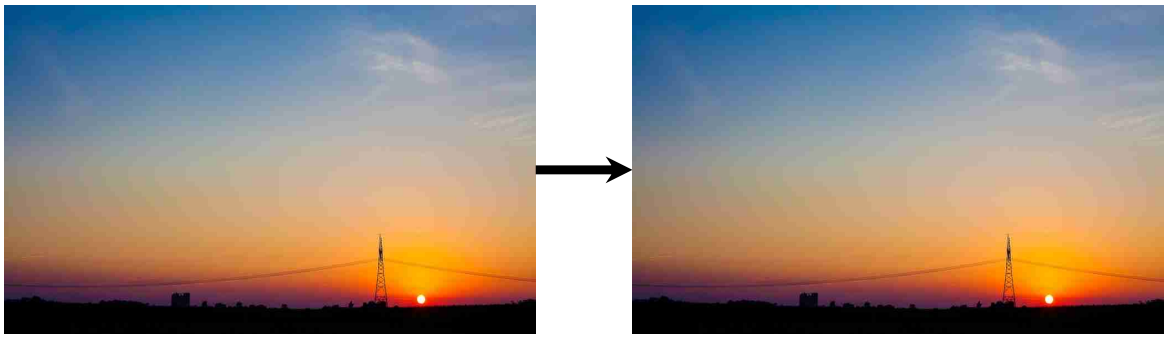
- Modular mode (lossless)
- VarDCT mode (lossy)
  - Uses Modular for the 1:8 LF and various uxiliary images
  - Variable-sized DCT (2x2 to 256x256, including non-square)
- JPEG recompression
  - uses a subset of VarDCT mode (DCT8x8 only)



JPEG XL (ISO/IEC 18181)



Numerically lossless transcoding



sunset.jpg
6173 bytes

reversible

sunset.jxl
3320 bytes

JPEG XL lossless compression efficiency

Summary		Size difference vs. JPEG XL (-e 9 -E 3 -I 1)						
Type	Corpus	WebP	WebP v2	FLIF	AVIF	PNG	Effort 9	Effort 7
Digital 2d Art	Art	16.8%	10.2%	5.8%	71.3%	47.7%	3.3%	8.3%
Digital 2d Art	FanArt	19.2%	10.2%	8.7%	51.1%	52.9%	2.4%	9.7%
Comics / B&W	Manga	21.1%	15.9%	6.0%	140.3%	53.9%	2.5%	10.5%
Pixel Art	PixelArt	12.7%	14.2%	32.4%	106.4%	46.1%	5.0%	18.8%
Emoji / Icons	Emoji	11.4%	6.0%	12.0%	56.0%	50.0%	3.2%	9.6%
Digital 2d Art	Pixiv	15.4%	10.2%	9.7%	38.0%	50.7%	2.6%	6.6%
Comics	ComixArt	20.4%	12.6%	6.0%	95.7%	58.3%	4.4%	12.2%
Game Assets	GameSets	13.3%	9.4%	11.9%	83.7%	48.9%	5.8%	19.7%
Game Screenshots	GameScr	13.1%	7.1%	5.8%	40.2%	41.3%	3.3%	7.0%
Photo	ITAP	10.5%	5.2%	2.2%	47.6%	40.6%	2.8%	5.2%
Photo	CLIC	11.9%	8.0%	4.0%	23.2%	41.1%	0.9%	2.6%
Photo	LPCB	13.8%	11.0%	5.3%	33.8%	33.4%	1.2%	2.2%
Digital 3d Art	LowPoly	16.1%	5.3%	3.9%	46.7%	43.8%	2.0%	10.1%
Fractal Art	Fractals	10.9%	7.6%	3.7%	47.6%	38.8%	5.6%	10.9%
Average		**14.8%**	**9.5%**	**8.4%**	**63.0%**	**46.3%**	**3.2%**	**9.5%**

Complexity (speed test)

Codec	Encode MPixel/s	Decode MPixel/s
JPEG XL cheetah (4 threads)	**49.753**	**132.424**
JPEG-libjpeg	9.013	11.133
JPEG-libjpeg-turbo	48.811	107.981
HEVC-HM-YUV444	0.014	5.257
HEVC-x265-YUV444	1.031	14.037
HEVC-x265-YUV444 (4 threads)	3.691	14.100

CPU: Xeon E5-2690 v4 CPU @ 2.60GHz

JPEG XL implementations

- ***libjxl:*** reference encoder/decoder
- ***fjxl:*** very fast lossless encoder, now integrated into libjxl (-e 1)
- ***libjxl-tiny:*** simplified encoder, model for hardware implementation
- ***J40:*** independent decoder implementation (single-file C)
- ***jxlatte:*** independent decoder implementation (Java)
- ***jxl-oxide:*** independent decoder implementation (Rust)
- ***hydrium:*** independent encoder implementation (C), focused on speed and low memory

- Already included in several products
  - Apple iPhone 16 Pro & 16 Pro Max
  - Samsung Galaxy S24/S25
  - Adobe Photoshop
  - ImageMagick
  - Apple OS (MacOS, iOS, iPadOS, WatchOS, etc.)
  - Safari Internet Browser
  - Firefox Internet Browser (behind flag)
  - Chrome Internet Browser (now removed)
  - Several other Internet Browsers
    - Pale Moon
    - Basilisk
    - Thorium
    - Floorp
    - Midori
    - Cromite
    - Epiphany

Joint Project between ISO/IEC/ITU

JPEG is a joint working group of the International Standardization Organization (ISO) and the International Electrotechnical Commission (IEC).

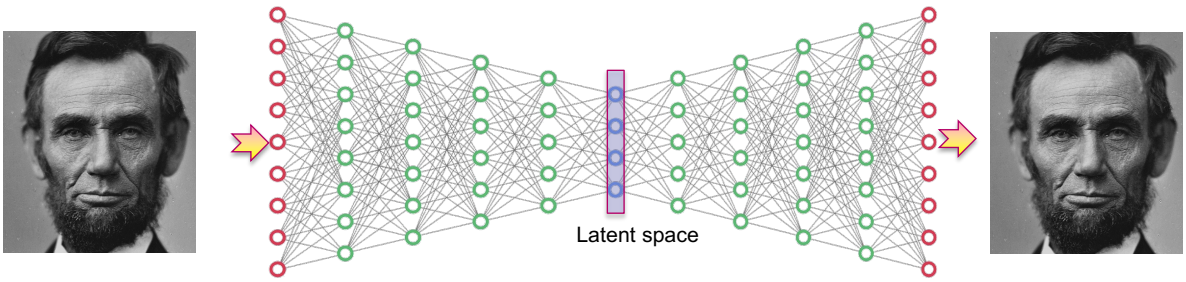
The word "Joint" in JPEG does not refer to the joint efforts of ISO and IEC, but to the fact that the JPEG activities are the result of an additional collaboration with the International Telecommunication Union (ITU).

From JPEG AI Call for Proposals: "The JPEG AI project is a joint standardization effort between ISO/IEC JTC1/SC29/WG1 and ITU-T SG21."

How to take advantage of AI in coding

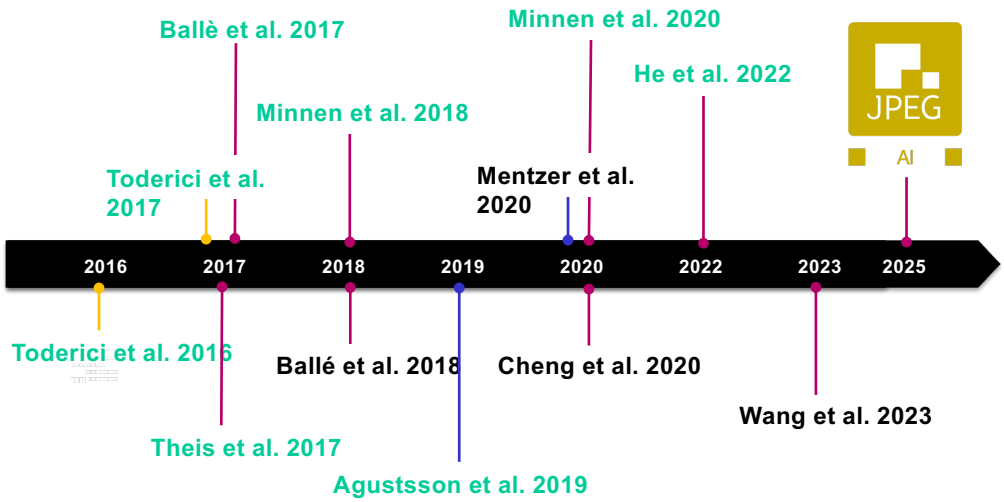
- Three possible alternatives
  1. AI assited codec optimization
  2. Component replacement by ML tools (e.g. NN)
  3. End-to-end autoencoders

A radically different coding architecture



Autoencoder

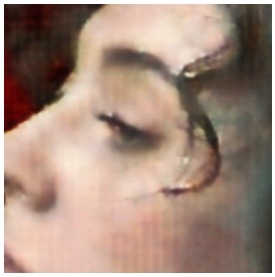
End-to-end image coding



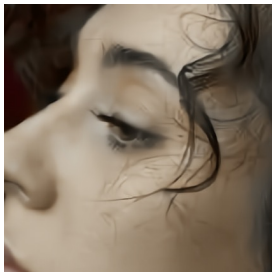
A radically new and powerful coding paradigm

JPEG – 0.08bpp

Toderici et al. – 0.06bpp



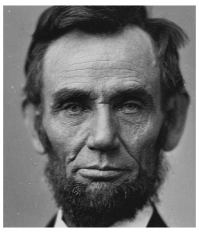
Ballè et. al. – 0.07bpp

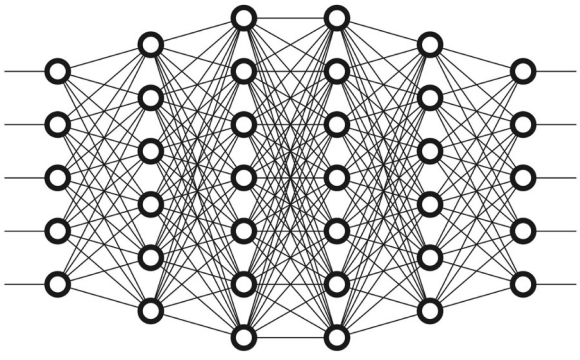


Mentzer et al.– 0.1bpp

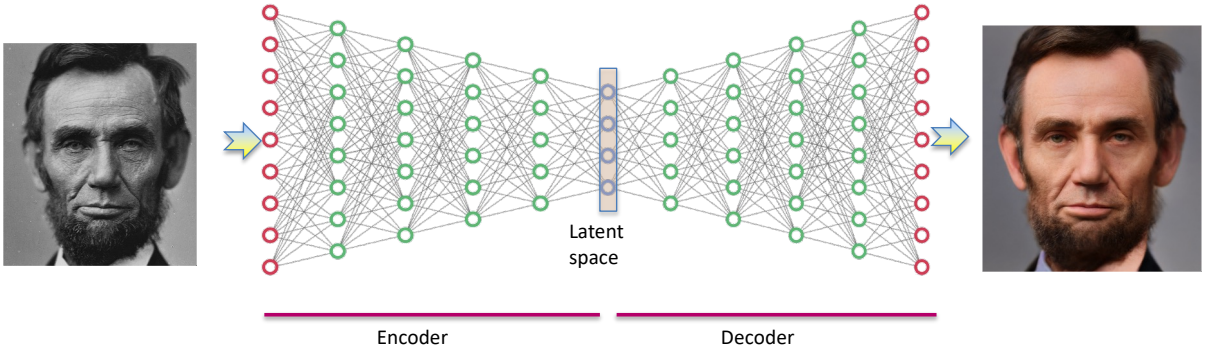
1992 2017 2018 2020

AI-powered image enhancement



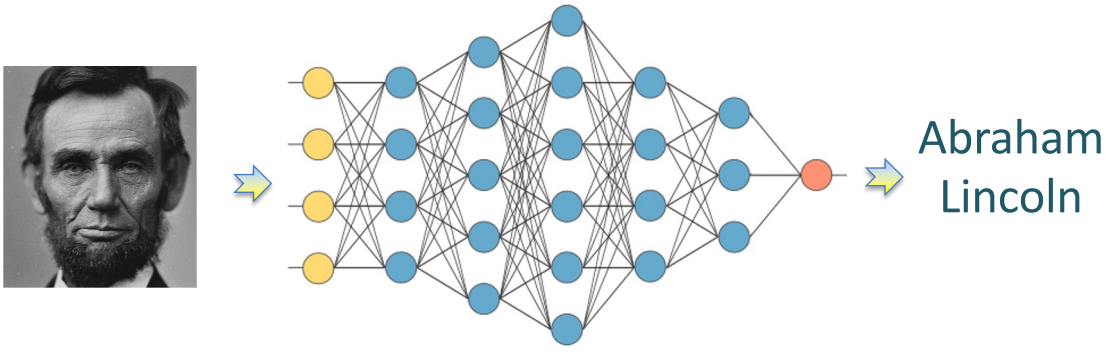


AI-powered image enhancement

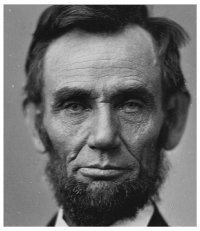


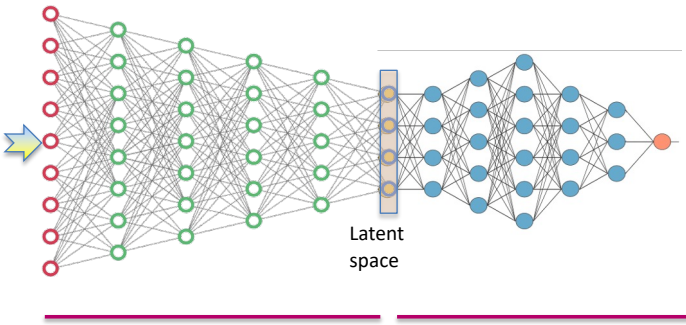
Autoencoder

AI-powered machine vision



AI-powered machine vision



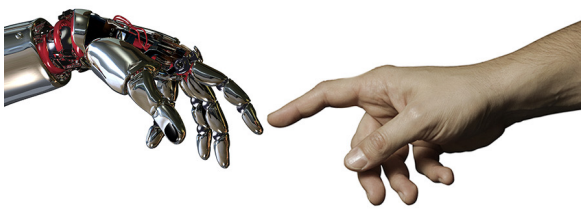


Abraham Lincoln

Autoencoder

Image coding for humans and machines

- There is more in AI based image coding that meets the eyes
  - AI is extensively used in image enhancement and machine vision
  - An image coding for machines and another for humans divides the ecosystem
  - Can we put both under the same framework?



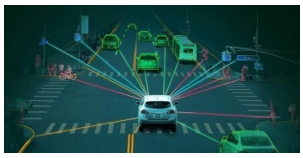
JPEG AI scope

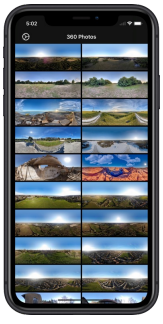
The JPEG AI scope is the creation of a learning-based image coding standard offering a **single-stream**, **compact**, compressed domain representation, targeting both **human visualization**, with significant compression efficiency improvement over image coding standards in common use at equivalent subjective quality, as well as effective performance for **image processing** and **computer vision** tasks, with the goal of supporting a **royalty-free baseline**

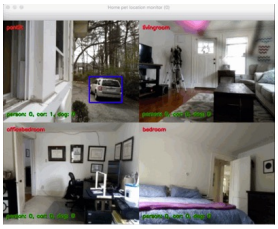
JPEG AI is the first coding standard that leverages artificial intelligence for superior coding efficiency while taking into account the requirements of AI-powered content processing and analytics

Applications & Use Cases

- **Mobile Imaging**
- **Cloud storage**
- **Visual surveillance**
- **Autonomous vehicles and devices**
- **Image collection storage and management**
- **Live monitoring of visual data**
- **Media distribution**
- **360º photo sharing**







Requirements

- **High coding efficiency** is important for many applications such as cloud storage or media distribution
  - *AI-powered architectures have demonstrated to be particularly efficient in coding*
- **Content understanding** is vital for many applications such as visual surveillance, autonomous vehicles, image collection management, etc.
  - *Objects may need to be recognized*
  - *Images may need to be classified for organization purposes*
  - *Actions or events may need to be recognized*
- **Content enhancement** is desirable in many applications such as in media distribution
  - *Noise can be reduced*
  - *Resolution can be increased*
  - *Colors can be corrected*
- Separate **content coding for machines** and **content coding for humans** hinders interoperability and increases complexity in applications that require both
  - *Why two codecs when one can do both?*
  - *In many applications, the same content is consumed by both humans and machines*
  - *Compatible with user-centric AI (human in the loop) approach*

JPEG AI strategy

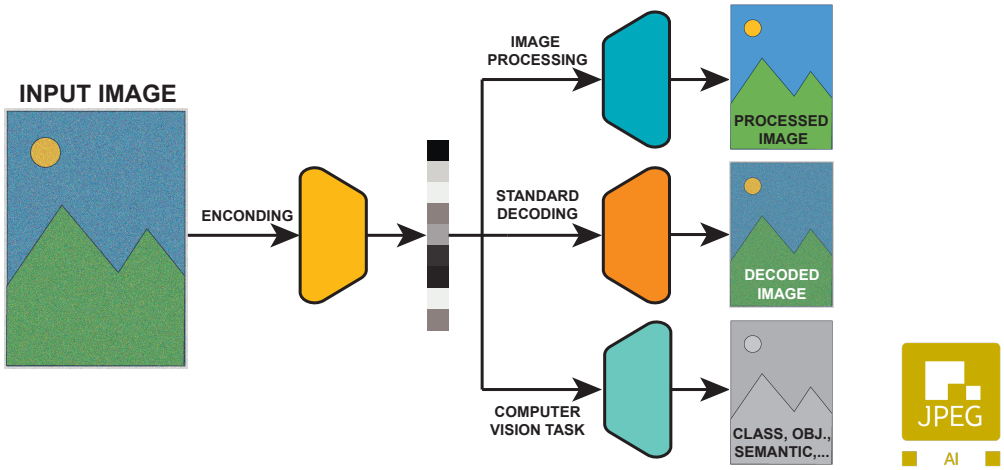
VERSION 1 (already published)

1. Several JPEG AI requirements with emphasis on compression efficiency

VERSION 2 (in progress)

1. JPEG AI requirements not yet addressed in Version 1, e.g. processing and computer vision tasks
2. Significantly improved tools for JPEG AI requirements already addressed in Version 1, e.g. compression efficiency

JPEG AI triple-purpose framework



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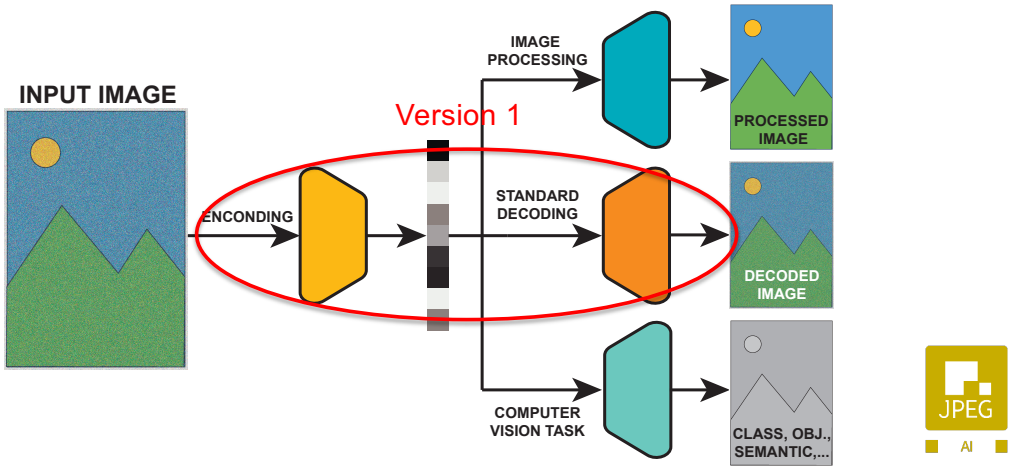
JPEG AI (ISO/IEC 6048, ITU-T Rec.840)



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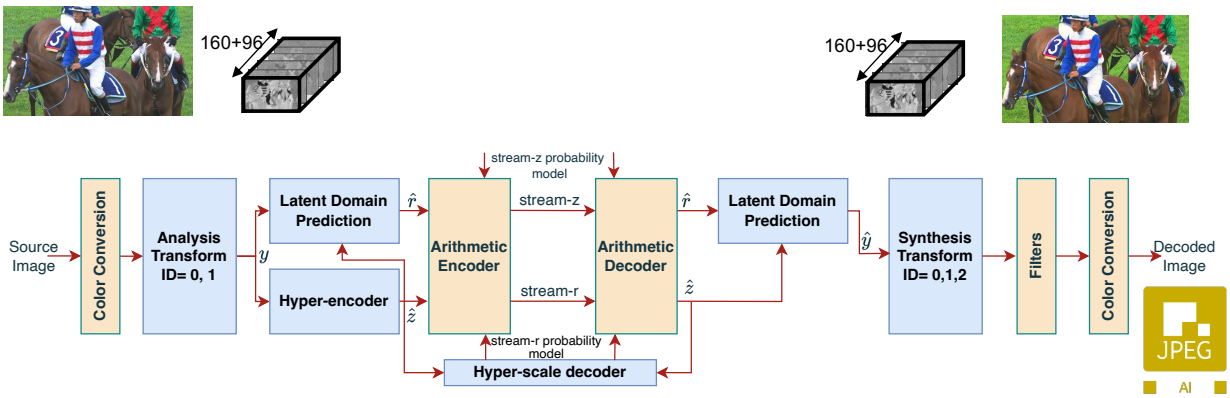
JPEG AI Version 1

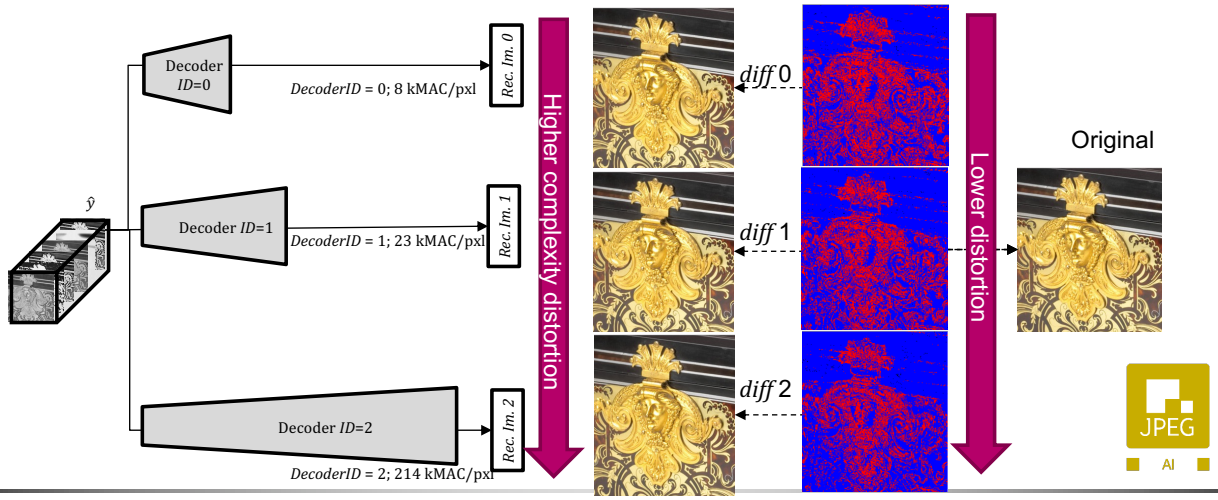
Part	Title	WD	CD	DIS	FDIS	IS
1	**JPEG AI: Core coding system**	-	23/11	24/04	-	24/10 → 25/06
2	JPEG AI: Profiling	-	24/07	25/01	-	25/07
3	JPEG AI: Reference software	-	24/07	25/01	-	25/07
4	JPEG AI: Conformance	-	24/10	25/04	-	25/10
5	JPEG AI: File format	-	24/07	25/01	-	25/07

ITU-T Rec. T.840.1 ISO/IEC 6048-1

JPEG AI Architecture



JPEG AI: Single Stream but Multiple Decoders



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Overall Performance

Test	BD-Rate AVG	Dec.			Enc.
		kMAC/pxl	*Time GPU, ×*	*Time CPU, ×*	*Time GPU, ×*
HEVC-SCC Intra	7.5%	-	0.8 (CPU)	0.8 (CPU)	0.8 (CPU)
VTM-11 Intra	0.0%	-	1 (CPU)	1 (CPU)	1 (CPU)
Enc0Dec0-tools-off	**-12.0%**	**8**	**0.36**	**1.05**	**0.0005**
Enc0Dec0-tools-on	-16.2%	14	0.41	2.4	0.0011
Enc0Dec1-tools-off	**-16.7%**	**23**	**0.38**	**2.1**	**0.0005**
Enc0Dec1-tools-on	-20.2%	28	0.41	3.3	0.0011
Enc1Dec2-tools-off	**-24.0%**	**212**	**0.61**	**214**	**0.0012**
Enc1Dec2-tools-on	-27.0%	215	0.64	215	0.0018

Codec	8K Encoding, s
JPEG	5
HEVC / H.265	2689
VVC / H.266	18725
JPEG AI	5 (Enc0) or 20 (Enc1)

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