The Art of Image Compression: JPEG and JPEG-2000 on Multispectral Satellite Imaging

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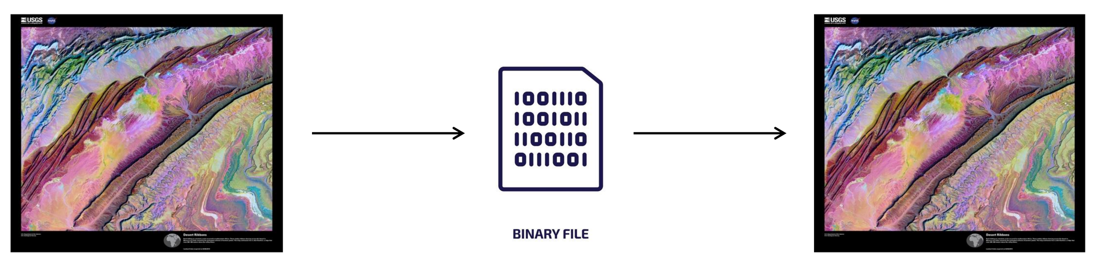
Introduction

Modern imaging systems generate extremely large, detail-rich files, but bandwidth and memory are limited. **Image compression** addresses this by converting images into bitstreams and encoding them, reducing file size. This saves transfer time and reduces storage requirements. Depending on the use case, compression can be lossless, reproducing the original image exactly, or lossy, achieving higher savings by discarding minor details that are barely perceptible to the human eye.



49.2 MB 4MB 20 MB

Image Compression Standards

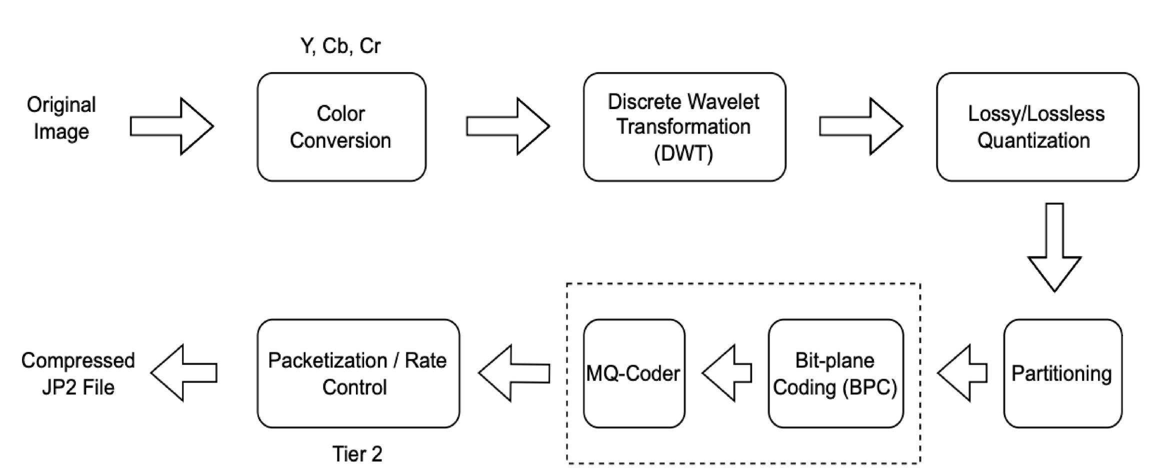
In this project, we implemented and studied two existing image compression standards—**JPEG and JPEG2000**.

JPEG: Standardized in 1992 to make digital photos smaller for storage, enabling practical sharing over limited bandwidth and small storage. JPEG has been the most widely used image compression standard in the world, with several billion JPEG images produced every day as of 2015.

JPEG2000: introduced in 2000 as the successor to JPEG, uses wavelet-based compression to achieve better image quality at lower file size and supports both lossy and lossless encoding. It also adds features like progressive transmission and region-of-interest coding, though its adoption has been limited by higher computational demands.

JPEG2000 Pipeline

The traditional JPEG2000 pipeline include color conversion, quantization, partitioning, bit-plane coding(BPC), MQ-coder, and packetization/rate control.



Implementation

We implemented a simplified, parallel JPEG2000 pipeline that kept most important structures.

Color Conversion: Convert RGB to YCbCr to separate brightness (Y) from color (Cb, Cr). This lets us keep Y sharp while compressing Cb/Cr, improving compression with little visible loss.

Discrete Wavelet Transformation (DWT):
Splits the image into multiple sub-bands: LL (coarse) and LH/HL/HH (detail) so that coarse structure and fine edges are separated. This concentrates energy in LL and enables band-dependent quantization for better compression.

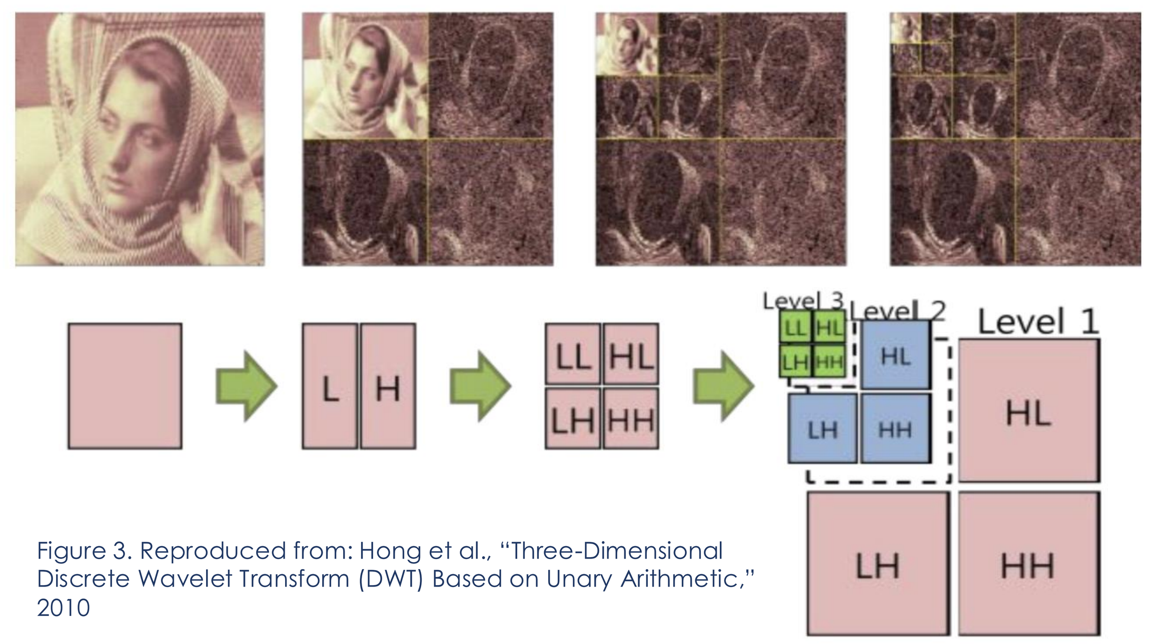
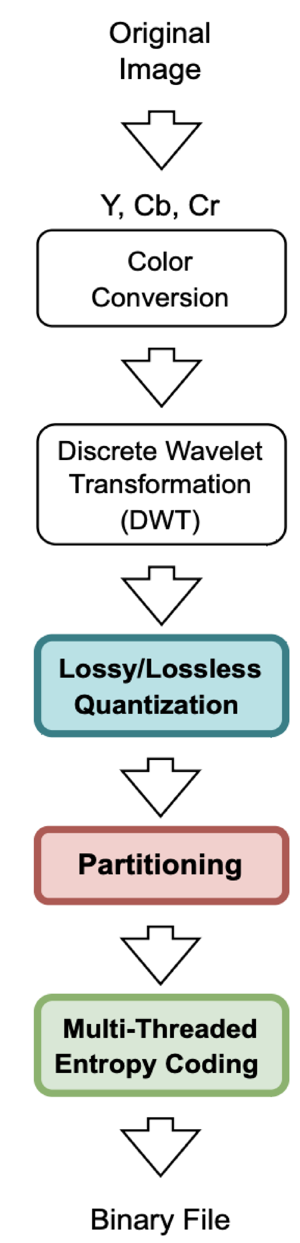


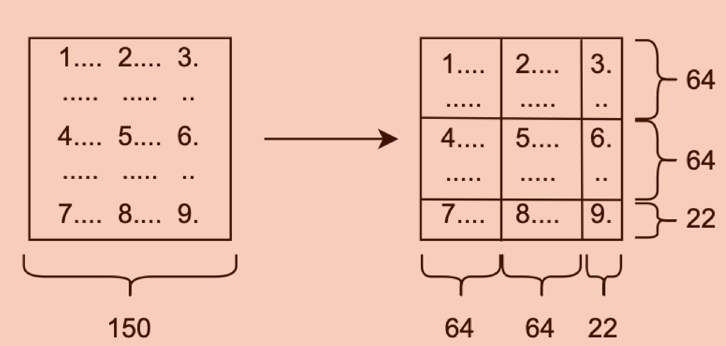
Figure 3. Reproduced from: Hong et al., "Three-Dimensional Discrete Wavelet Transform (DWT) Based on Unary Arithmetic," 2010



Quantization:
- DWT splits the image into LL (more important) and HL/LH/HH (less important) bands.
- Use smaller steps for LL to preserve precision, larger for HL/LH/HH to save memory.
- Converts floats to integers, shrinking value range and storage with minimal visible loss.

$$Q(x,\Delta,\delta) = \begin{cases} \operatorname{sgn}(x)\left\lfloor \dfrac{|x| - (\delta-1)\Delta}{\Delta} \right\rfloor, & \text{if } |x| \geq \delta\Delta, \\ 0, & \text{otherwise.} \end{cases}$$

Partition:
- Split quantized coefficients into fixed blocks.
- More uniform stats (less unique coefficient) → better entropy coding.
- Blocks encode independently → multi-threading (faster processing).



Multi-threaded Entropy coding:
- Encode each block separately in parallel.
- Encoding method chosen by the block's feature.
- Low-variation/repetitive blocks → DEFLATE (LZ77 + Huffman).
- Blocks with more unique coefficients → arithmetic.

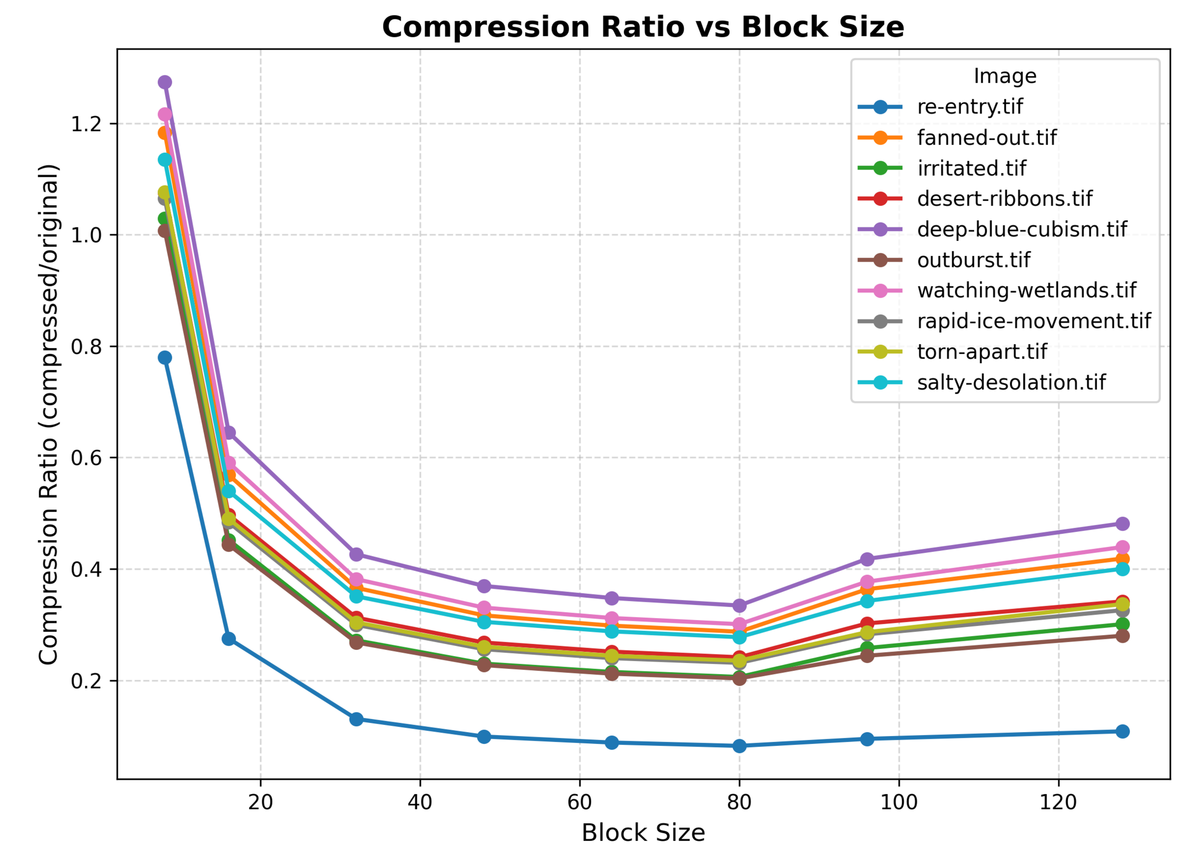
Experiment Set up & Results

We ran two experiments on 10 images from the Earth As Art collection [3], provided by the USGS Earth Resources Observation and Science (EROS) Center.

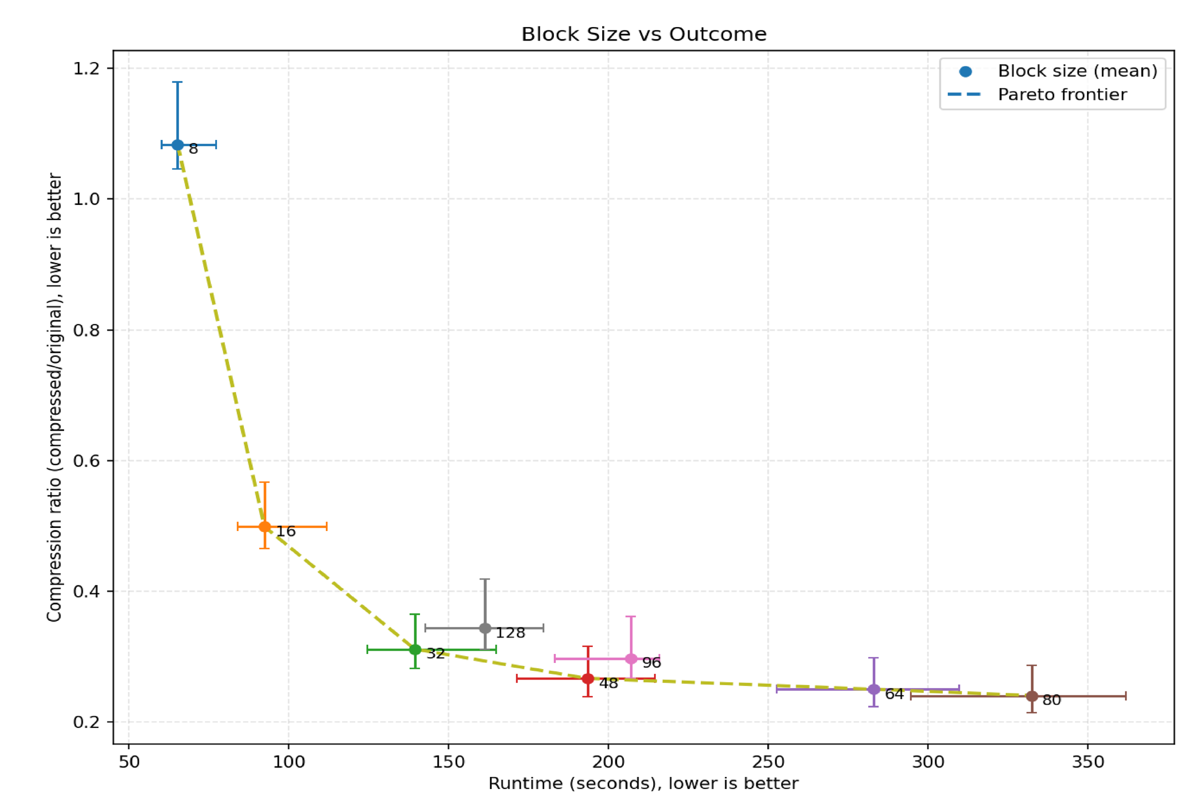
1. We varied the partitioning **block size** and measured its impact on **runtime** and **compression ratio**.

Key Metric: Compression Ratio: Ratio of compressed file size to the original file size. A smaller value indicates stronger compression and a smaller output file.

Why block size matters:
- **Entropy efficiency:** Changing block size changes the number of unique values within a block, which affects entropy coding efficiency.
- **Side information:** Each block includes additional data (e.g., size, encoding method), so having more blocks increases the amount of side information in the final compressed file.



Effect of block size on compression ratio



Effect of block size on compression vs. runtime

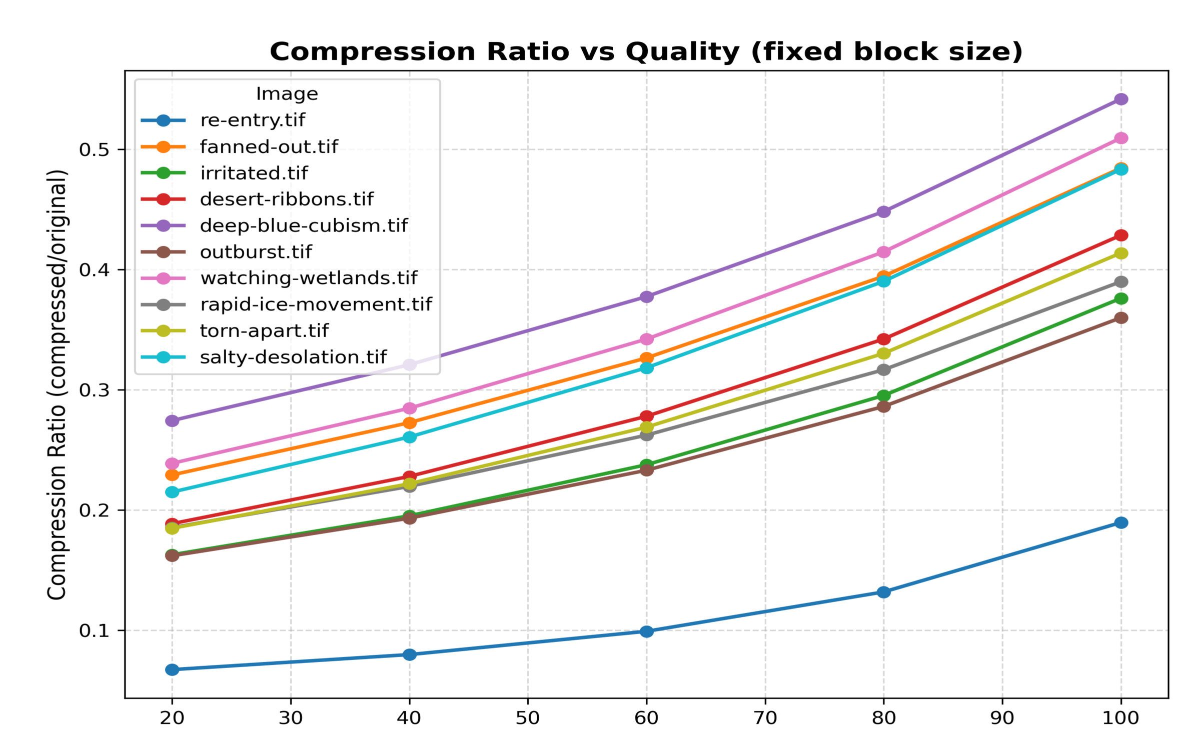
2. We vary the **quality factor** and measure its impact on pipeline **runtime**, **compression ratio**, and **PSNR.**

Key Metric: PSNR (Peak Signal-to-Noise Ratio): Measures reconstruction quality relative to the original image. Higher PSNR values indicate better image fidelity and less distortion.

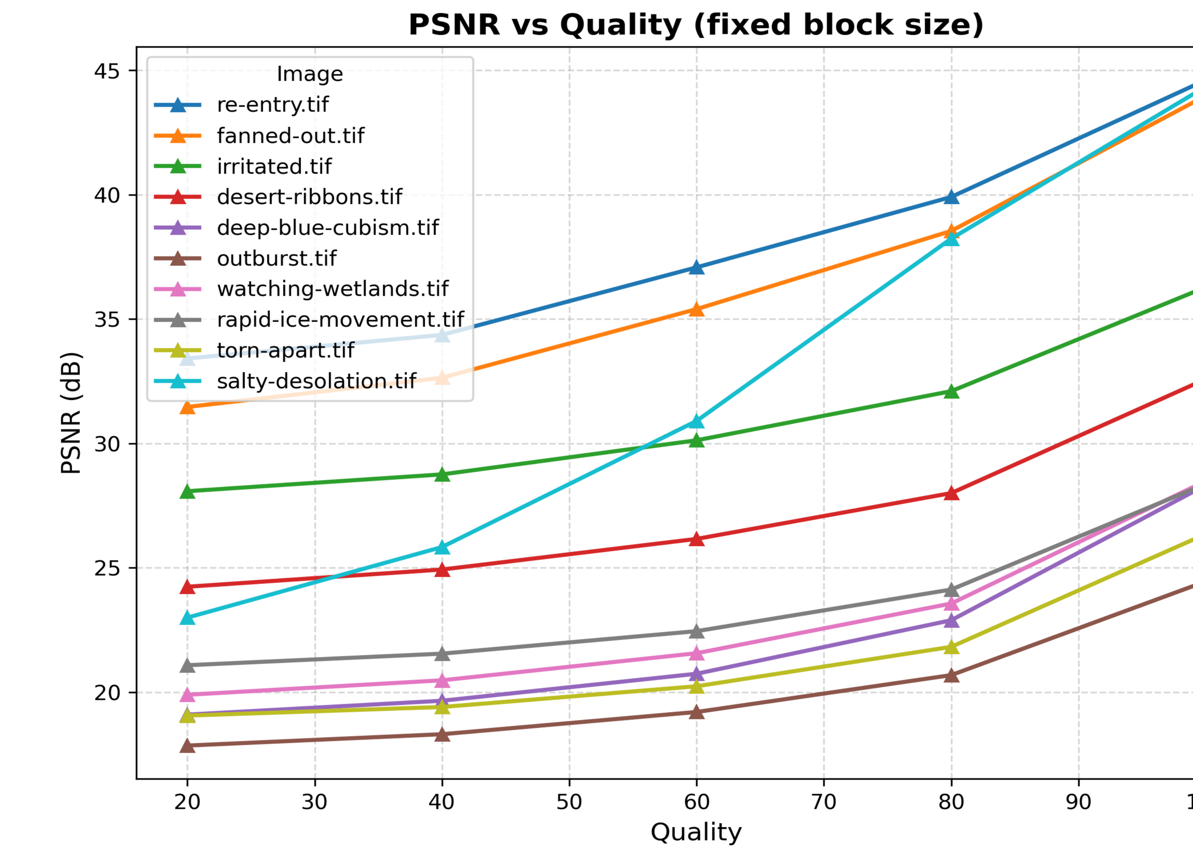
Why quality factor matters:

Quantization step: The quality factor determines the quantization step size. Higher quality uses smaller step values, preserving more detail but producing larger files and higher compression ratios.

Observed trade-offs: Changing the quality factor alters runtime and compression ratio, and it also shifts the details in the image, as reflected by the chosen metric.



Effect of quality on compression ratio



Effect of quality on Peak signal-to-noise ratio (PSNR)

Conclusion

Block size effects:
•Compression ratio decreases as block size increases up to around 80 px, then rises again.
•Small blocks run faster but use more memory due to side information overhead.
•Very large blocks have lower entropy coding efficiency due to too many unique coefficients.
•Optimal trade-off: 48–64 px blocks.

Quality factor effects:
•Higher quality yields larger files but stays closer to the original image.
•Lower quality factors compress better but introduce visible artifacts.
•Overall, results show a trade-off between compression efficiency and reconstruction quality.

Future Directions

•Investigate why certain images required less time to compress and achieved a higher compression ratio.
•Vary the mix of DEFLATE and adaptive arithmetic coding to measure impacts on entropy-coding efficiency and compression ratio.
•Implement Tier-2 packetization and JP2 output for rate control for more precise results.
•Add EBCOT optimizations to improve accuracy and efficiency.

Acknowledgement

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Reference

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