The Art of Image Compression: An Analysis of the Discrete Wavelet Transform in the JPEG2000 Algorithm

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PROJECT OVERVIEW

Image Compression Basics

- **Image compression algorithms** are developed to transmit files quickly and store them efficiently
- Main Goals: maintain reasonable **image quality** with a **fast** and **effective** approach

Our Project

Motivated by satellite images – large, high-resolution files which require compression for storage/transmission -- we have built our **own implementations** of the **JPEG** (Anika and Kritika) and **JPEG2000** (Leon and myself) image compression pipelines.

BASIC JPEG2000 PIPELINE

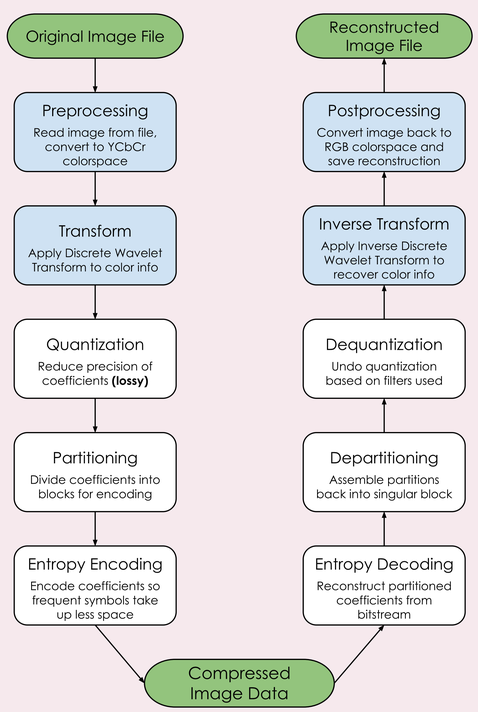

Fig. 1: Simplified JPEG2000 pipeline. Blue-shaded portions represent my contributions.

DISCRETE WAVELET TRANSFORM

The **Discrete Wavelet Transform** is a mathematical transformation which breaks down data into sets of **coefficients.** On a 2D image, each application of DWT results in a set of **approximant** coefficients and three sets of **detail** coefficients**.** The approximants represents the **average** value of each group of pixels, while the details represent the **differences** from those averages.

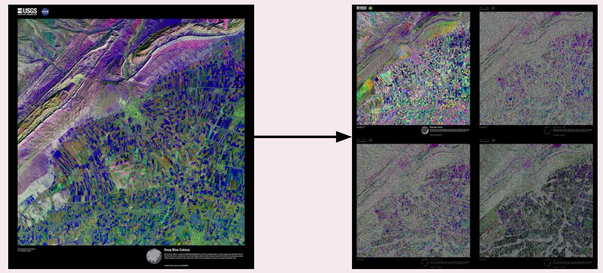

Fig. 2: Example image from dataset before and after application of single-level DWT.

Why It Works: Pixels in an image tend to convey very similar information to the pixels around them. As a result, the detail coefficients tend to be smaller numbers (oftentimes close to 0), making them **highly compressible** later in the pipeline.

By performing DWT repeatedly on the resulting approximant coefficients, **multi-level deconstruction** allows for most of the image to be transformed into details.

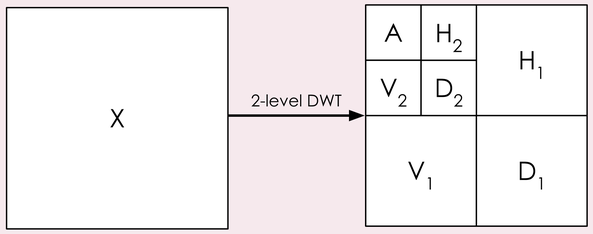

Fig. 3: Diagram representing an array of data before and after 2-level DWT is applied.

EXPERIMENT SETUP + RESULTS

Dataset

We ran experiments on images from the **Earth as Art** collection of satellite images from the Earth Resources Observation and Science Center of the United States Geological Survey [1].

Original images are **3900x4200 pixels** and roughly **46.8MB** when uncompressed.

Key Metrics

- **Compression Ratio:** The size of the compressed file relative to the original file
- **Encoding Runtime:** The running time of our algorithm's encoding process, in seconds
- **Peak Signal-to-Noise Ratio:** A holistic measure of the pixel-by-pixel difference between the original and reconstructed image, measured in dB

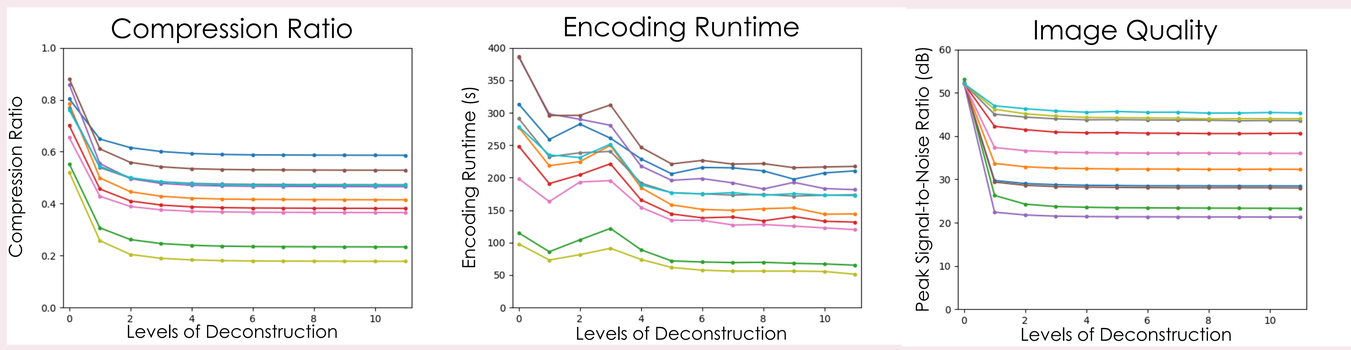

Fig. 4: Metrics per decomposition level on ten images from dataset. Each line represents data from one image.

DISCUSSION

Key Results

- Predictably, images which did not have DWT applied retained high quality (PSNR > 50), at the cost of a long runtime and very little data compression
- **Compression ratio** improves as higher level deconstruction is applied, but there are severe **diminishing returns** after **~4-5 levels**
- **Encoding runtime** sees similar diminishing returns past **5-level DWT**, but with an increase in runtime at **3-level DWT** without improvements in other metrics
- **Image quality** is considerably worse after even single-level DWT, but changes remain **largely insignificant** through **any level** of decomposition

Conclusions

- The basic effect of DWT in the pipeline is a **sacrifice in image quality** for **significant returns on runtime and compression ratio**
- **4-level or 5-level DWT** appears to be a solid compromise on this dataset, preventing further loss in image quality while providing similarly effective compression to max-level DWT

FUTURE WORK

- Understanding what image properties affect the reduction in quality with DWT
- Investigating why 3-level DWT takes longer to run on most images
- Using other datasets to see if trends hold

Acknowledgements

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References

[1] *Earth As Art | U.S. Geological Survey*. https://www.usgs.gov/centers/eros/earth-art. Accessed 29 Sep. 2025.

[2] Christopoulos, C., et al. "The JPEG2000 Still Image Coding System: An Overview," *IEEE Transactions on Consumer Electronics*, vol. 46, no. 4, Nov. 2000, pp. 1103–27. *DOI.org (Crossref)*, https://doi.org/10.1109/30.920468.

[3] CHAPTER 12: THE JPEG2000 IMAGE COMPRESSION STANDARD. *learning.oreilly.com*, https://learning.oreilly.com/library/view/discrete-wavelet-transformations/9781118979273/c12.xhtml. Accessed 10 Oct. 2025.