Transform Coder Classification for Digital Image Forensics

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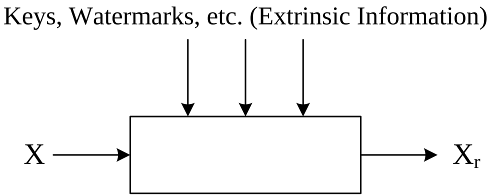
Introduction

- Today's topic: Image compression forensics.
- Multimedia security is typically extrinsic in nature.



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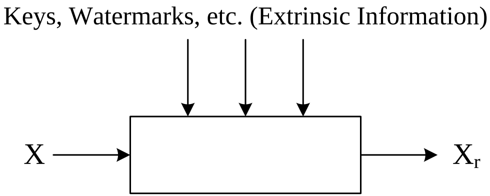

- Alternative: Examine the intrinsic information of a signal.

(Use the intrinsic information in X_r.)

Motivation

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- **Datapath Integrity.** Validate the steps taken to process data, and assess the trustworthiness and reliability of these operations.
- **Picture Integrity.** Picture content is of crucial importance in many scenarios. Verify the similarity between the digital photograph and the actual scene.
- Other motives: Detection of patent infringement, quality assurance, rate control, and restoration.

Problem Formulation

Forensic problem for image compression:

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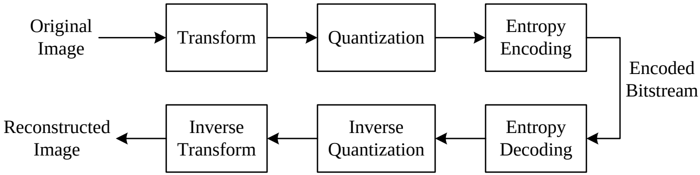
- Given only a raw image, perform forensic analysis upon the image by examining *intrinsic fingerprints*.
- What compression has been performed, if any? To what *family* does the source coder belong?
  - What *transform method*, if any, was used? DCT? DWT? Other?
- What are the parameters of the coding scheme?
- Establish a confidence measure.

Main contribution: Classification of the **transform method** used during image compression.

System Model

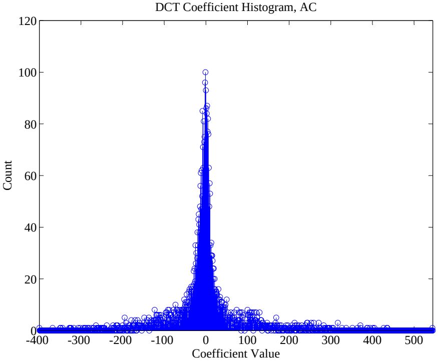
Consider a generic transform coding scheme:

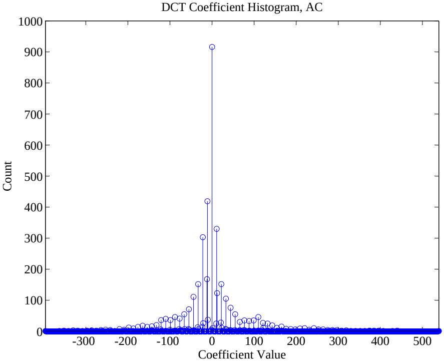


Fundamental question: *For each source coder, where, and in what domain, does the loss occur?*

Transform Coefficient Distributions

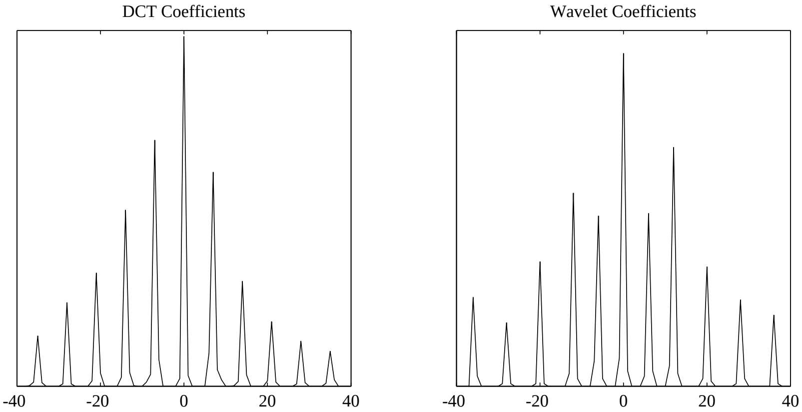
A decompressed image, transformed properly, will exhibit evidence of quantization through histogram peaks.





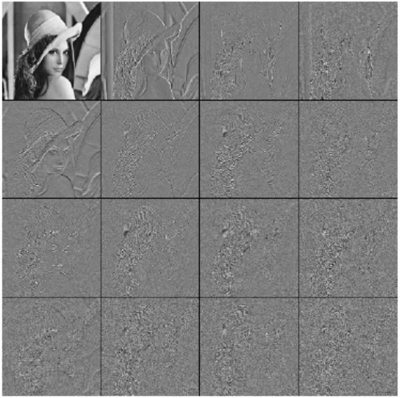
Left: Transform coefficient histogram before compression.
Right: Transform coefficient histogram after compression.

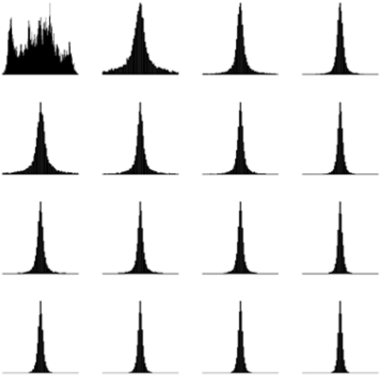
Peaks appear in the histogram of quantized wavelet coefficients, as well.



Subband Representations for Block Transforms

DCT coefficients can also be reorganized into subbands[1].
Example, 4-by-4 DCT:





[1] Z. Xiong *et. al.*, IEEE Signal Processing Letters, Nov. 1996

Histogram Fitting

Goal: For each subband, measure the distance between the probability distributions of the transform coefficients before quantization and the observed transform coefficients.

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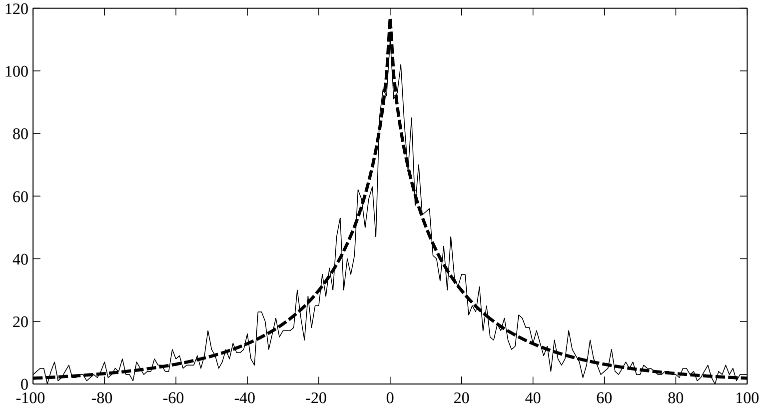
- Problem: We don't have the histogram of the original, unquantized coefficients.
- Solution: Use a least-squares fit to a generalized Gaussian distribution.

$$\begin{array}{ll} \min_{\gamma,\lambda,\nu} & \sum_k \left(p(k) - \gamma \exp(\lambda |k|^\nu)\right)^2 \\ \text{s.t.} & \gamma > 0, \lambda < 0, \nu > 0 \end{array}$$

Solve using numerical optimization (e.g., modified Newton method).

Coefficient histogram of transform coefficients from one subband of an uncompressed image, along with nonlinear least-squares fit:



Distance Measure

Let $\hat{p}(k)$ be the histogram of the inverse quantized coefficients.

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- Relative entropy: $D(\hat{p}||p) = \sum_k \hat{p}(k) \log \frac{\hat{p}(k)}{p(k)}$.
- Intuitively, the relative entropy is the extra number of bits required to encode a source with distribution $\hat{p}$ given a code for distribution p.

$$E_{\hat{p}}\left[\log \frac{1}{p}\right] = H(\hat{p}) + D(\hat{p}||p)$$

If this value is high, then the image has most likely been compressed.

Algorithm

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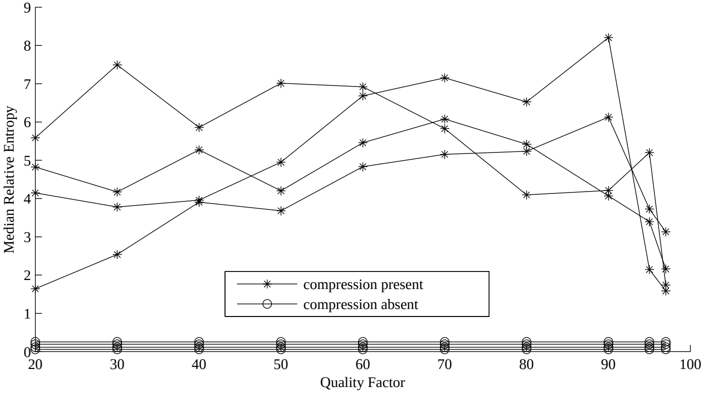
3. Approximate the histogram of the original, unquantized coefficients using nonlinear least-squares.
4. Calculate the relative entropy between the observed and the approximated original histogram.
5. Find the mean/median value among the relative entropies from all subbands. If this value is high, then the tested transform is the one used during compression.

Results

Four JPEG-compressed images with block size of 8.
Distance (relative entropy) vs. quality factor:



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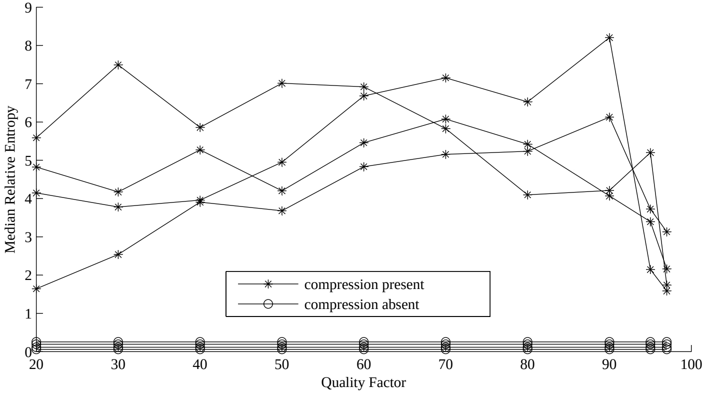

Strong separation found between compressed and uncompressed images.

- Block transforms tested: DCT, Hadamard, Slant (block size = 8, quality factor = 60)
- Wavelet transforms tested: 5/3, 9/7, 17/11

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Average distance scores (rows indicate true transform, columns indicate tested transform:

	DCT	Hadamard	Slant	5/3	9/7	17/11
DCT	**2.198**	1.099	1.631	0.160	0.159	0.148
Hadamard	0.745	**2.208**	1.619	0.274	0.158	0.147
Slant	**2.805**	1.563	**2.249**	0.212	0.154	0.156
5/3	0.147	0.091	0.137	**4.099**	0.664	0.402
9/7	0.174	0.081	0.123	0.784	**4.186**	1.902
17/11	0.191	0.081	0.120	0.454	1.869	**4.216**

Classification is successful among transform methods.

Can two different transforms produce the same histogram?

- Yes, if transform computations are numerically similar.
- Example:

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$$D_1^T D_2 = \begin{bmatrix} 0.9987 & -0.0354 & 0.0354 & 0.0013 \\ 0.0354 & 0.9987 & 0.0013 & -0.0354 \\ -0.0354 & 0.0013 & 0.9987 & 0.0354 \\ 0.0013 & 0.0354 & -0.0354 & 0.9987 \end{bmatrix} \approx I$$

Classification still achieved!

Conclusions

We proposed a method to classify the transform method used during transform coding of digital images.

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Overall problem: **Image compression forensics**.

Thank you.

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