

An SVD Approach to Forensic Image Resampling Detection

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UniversidadeVigo

Problem Description

The presence of **forged digital contents** in the **media, social networks** or flowing through the **Internet** has become prevalent these days.

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Example



Which of these two images is the genuine one?

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Example



Forged image



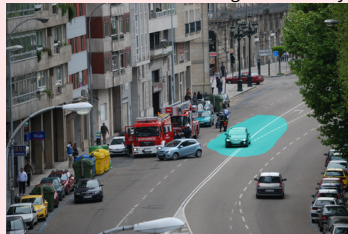
Original image

Problem Description

The presence of **forged digital contents** in the **media**, **social networks** or flowing through the **Internet** has become prevalent these days.

How to perform this image manipulation?

1. Motivation: define the region to modify



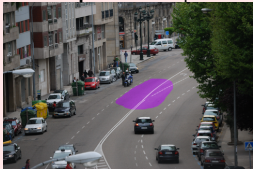
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Problem Description

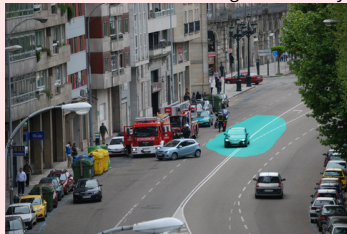
The presence of **forged digital contents** in the **media, social networks** or flowing through the **Internet** has become prevalent these days.

How to perform this image manipulation?

2. Find a patch to tamper with



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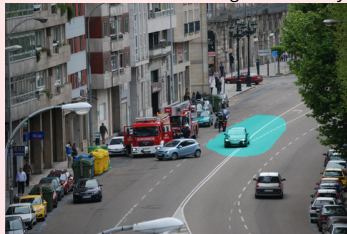
2. Find a patch to tamper with



3. Adapt the region to the scene

★ A resampling operation is needed!

1. Motivation: define the region to modify



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How to perform this image manipulation?

2. Find a patch to tamper with



3. Adapt the region to the scene

★ A resampling operation is needed!

1. Motivation: define the region to modify



4. Paste the region

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Example



Example of analysis

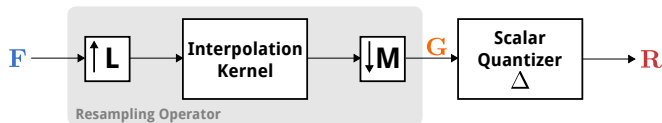


Forged image

Forensic Image Resampling Detection
will highlight resampling inconsistencies

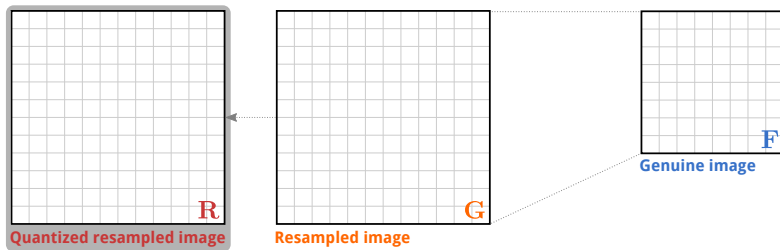
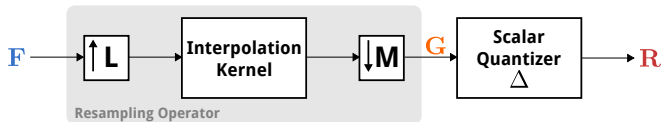
Basic Modeling of Image Resampling

Basic block flow diagram for a resampling operation by $\xi = \frac{L}{M} > 1$:



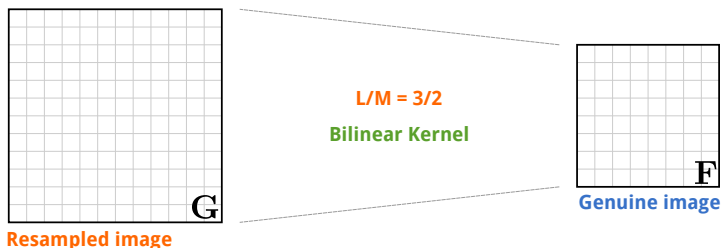
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Basic block flow diagram for a resampling operation by $\xi = \frac{L}{M} > 1$:



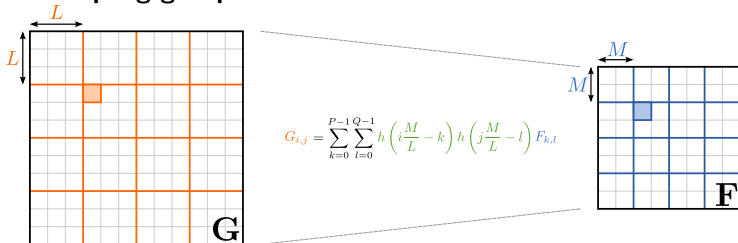
Analysis of Image Resampling

Example: resize an image by $\xi = \frac{3}{2}$ with bilinear kernel.



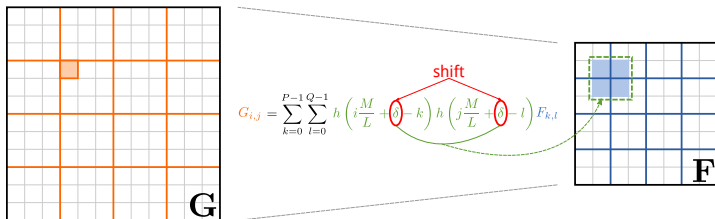
Analysis of Image Resampling

1. Resampling grid position:



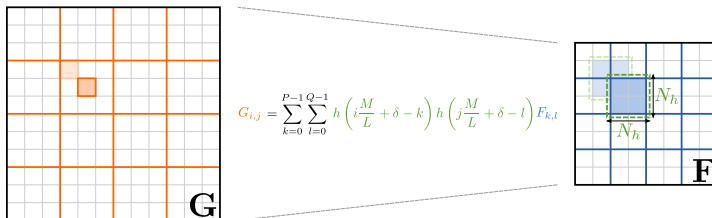
Analysis of Image Resampling

1. Resampling grid position: a shift is usually considered.



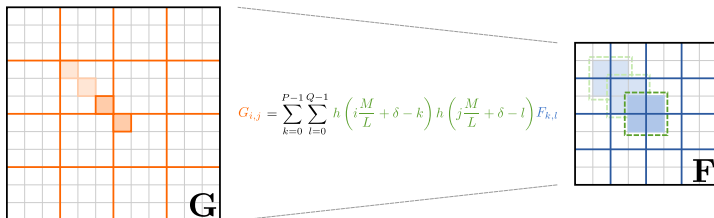
Analysis of Image Resampling (II)

2. Resampled pixel calculation: N_h represents the length of the kernel.



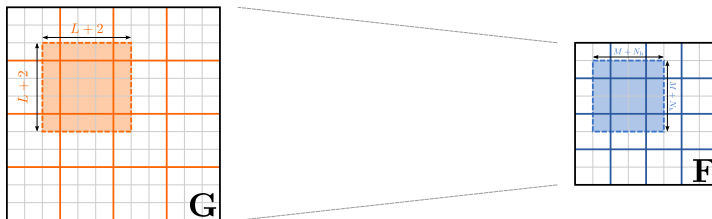
Analysis of Image Resampling (II)

2. Resampled pixel calculation: border pixels use the same samples.



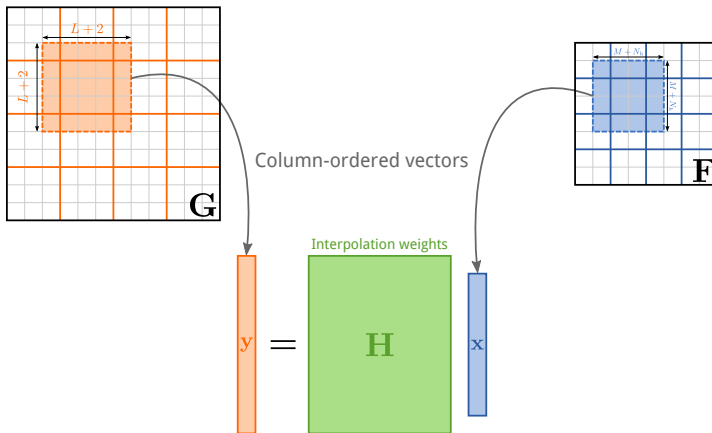
Analysis of Image Resampling (III)

3. Periodic linear relation: each block is always computed in the same way.



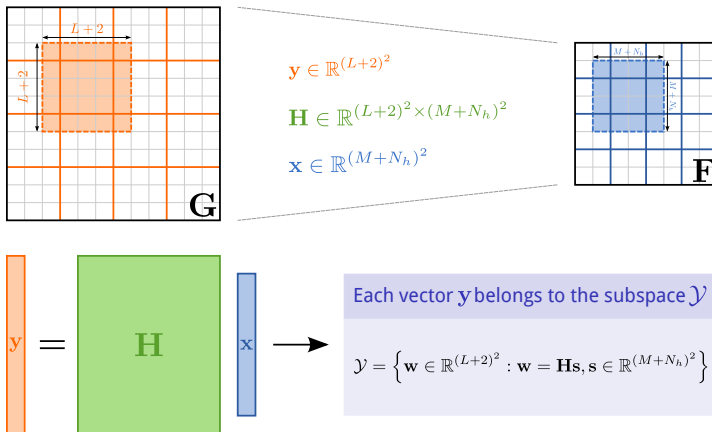
Analysis of Image Resampling (III)

3. **Periodic linear relation:** the following linear transformation arises.



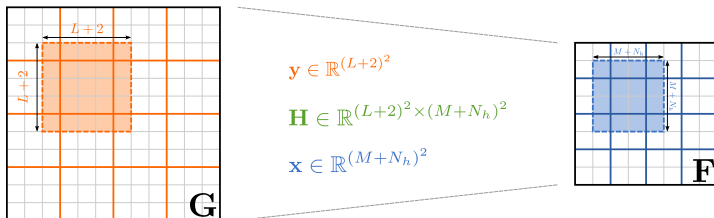
Analysis of Image Resampling (III)

3. Periodic linear relation:



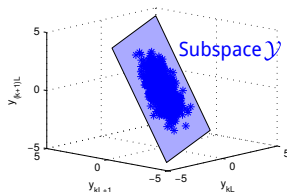
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3. Periodic linear relation:



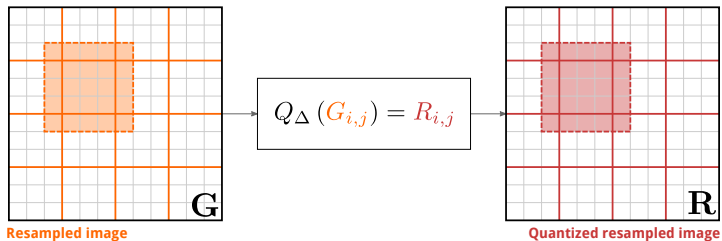
Example (1-D): $L/M = 2, x_i \sim \mathcal{N}(0, 1)$

$$\begin{bmatrix} y_{2k} \\ y_{2k+1} \\ y_{2k+2} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0.5 & 0.5 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_k \\ x_{k+1} \end{bmatrix}$$



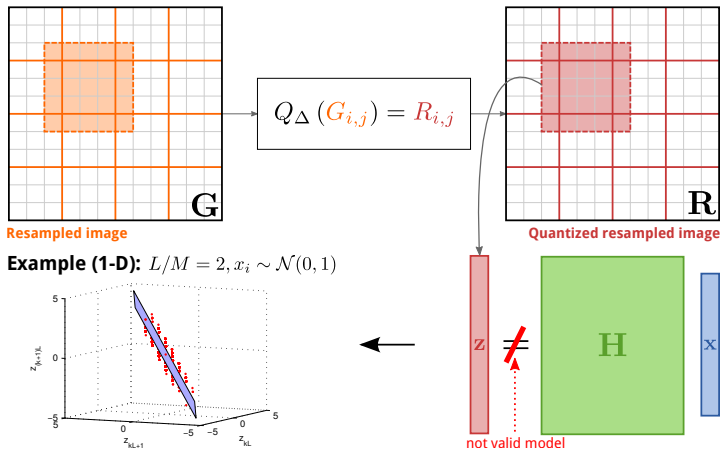
Analysis of Image Resampling (IV)

4. Quantization:



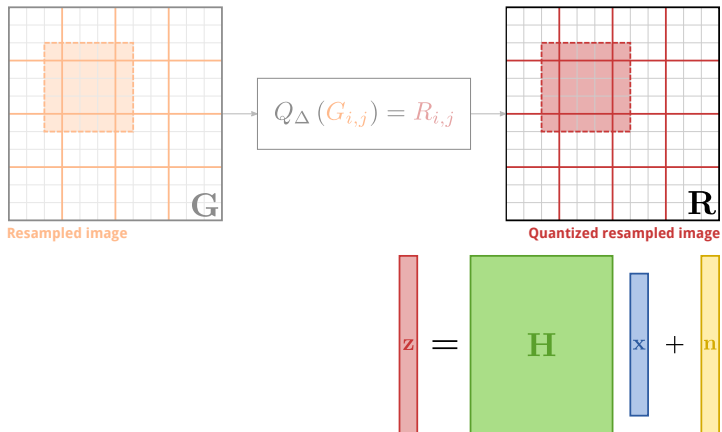
Analysis of Image Resampling (IV)

4. **Quantization:** previous linear model is no longer valid.



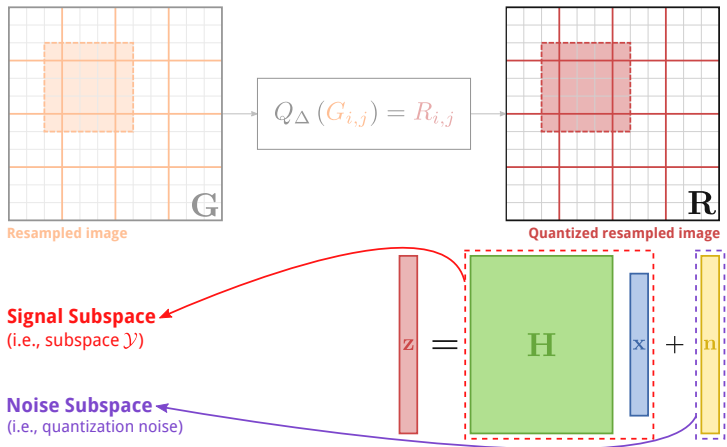
Analysis of Image Resampling (IV)

4. Quantization: a noise component is added to the model.



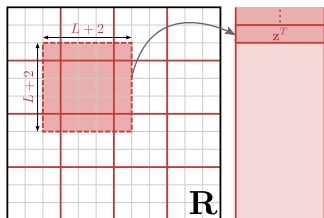
Analysis of Image Resampling (IV)

4. Quantization: upsampled images embody two subspaces.



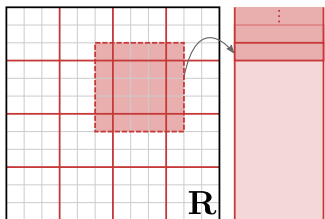
Subspace Decomposition through SVD

Building the observation matrix $\mathbf{Z}_K$: scan each $(L+2) \times (L+2)$ block.



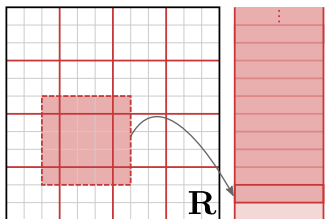
Subspace Decomposition through SVD

Building the observation matrix $\mathbf{Z}_K$: stack successive blocks.



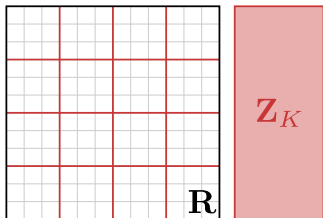
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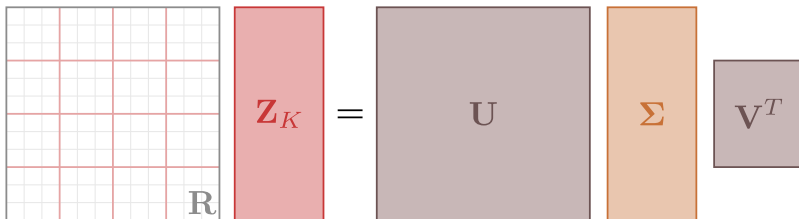
Subspace Decomposition through SVD

Building the observation matrix $\mathbf{Z}_K$: it yields a $K \times (L + 2)^2$ matrix.



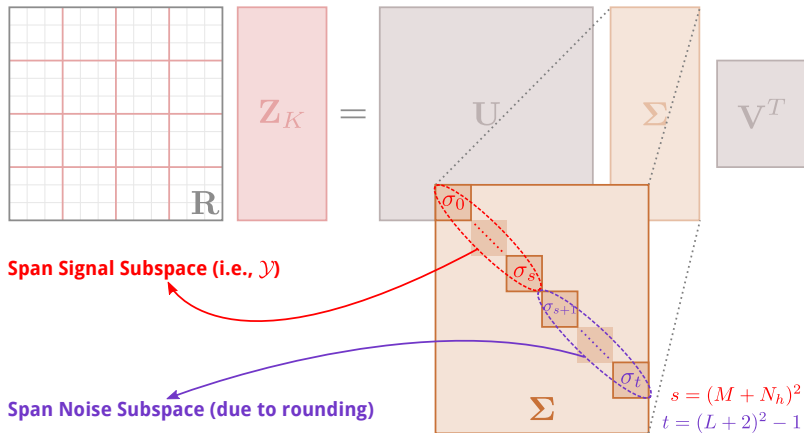
Subspace Decomposition through SVD

Representation of Z_K through its Singular Value Decomposition:



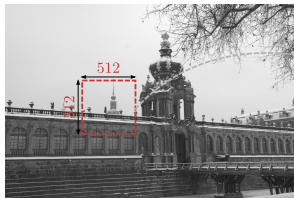
Subspace Decomposition through SVD

Subspace decomposition:

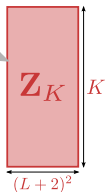


Subspace Decomposition through SVD

Example: resized image by $\xi = \frac{L}{M} = \frac{7}{5}$ and bilinear kernel ($N_h = 2$).



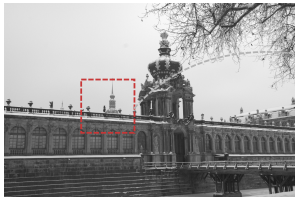
Quantized resampled image



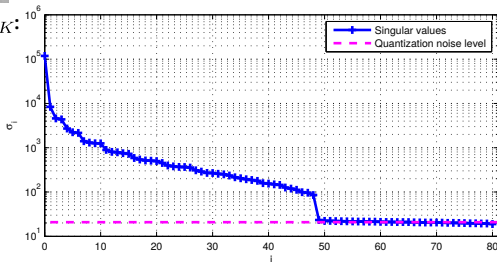
- **Space dimension:**
 $(L + 2)^2 = 81$
- **Subspace dimension:**
 $(M + N_h)^2 = 49$
- **Quantization noise level:**
 $\sqrt{K\sigma_n^2}, \sigma_n^2 = \frac{\Delta}{12}, (K = 5184, \Delta = 1)$

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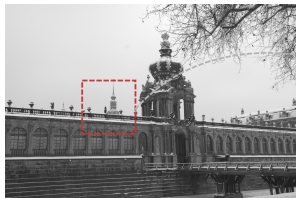


Evolution of Singular Values of Z_K :



Subspace Decomposition through SVD

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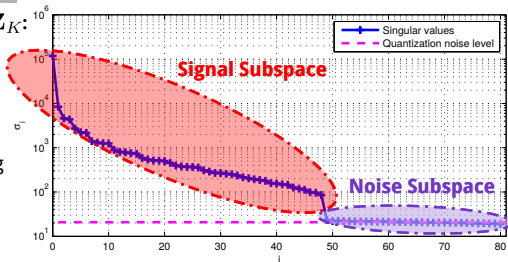
Evolution of Singular Values of Z_K :

★ **Pros:**

- Good **distinguishability** between subspaces.

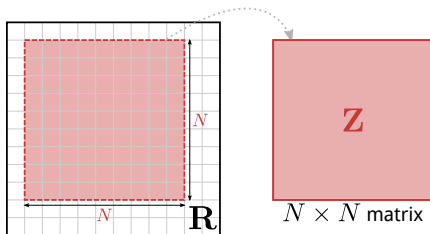
★ **Cons:**

- **Alignment** with resampling grid is needed.
- **Knowledge** of L .



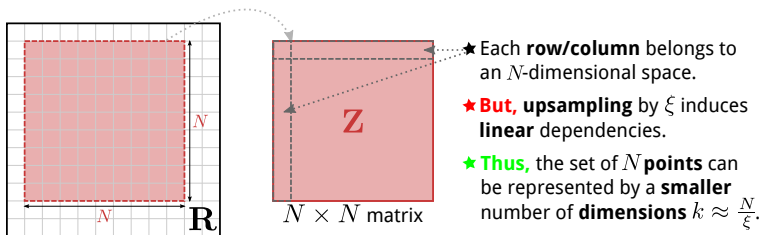
Practical Solution

Analysis of a block of $N \times N$ samples:



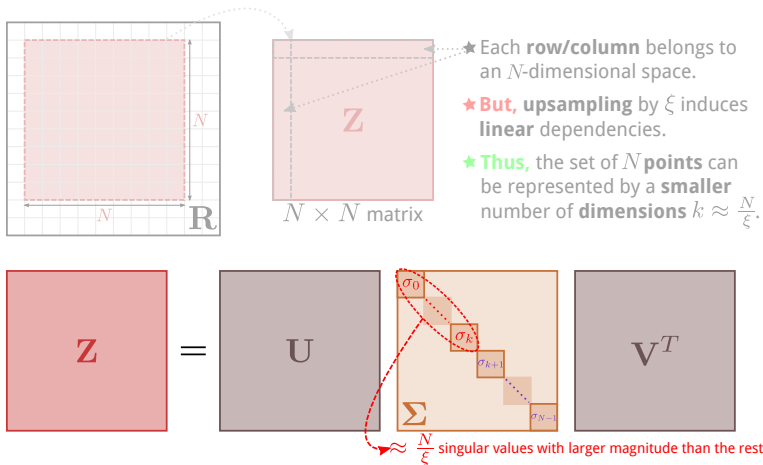
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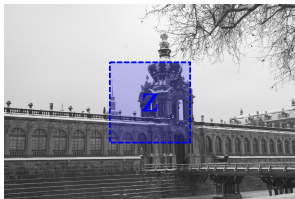
Practical Solution

Singular Value Decomposition of matrix Z :

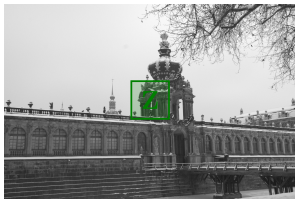


Practical Solution

Example: non-resampled vs. resampled images (center 512×512 block).

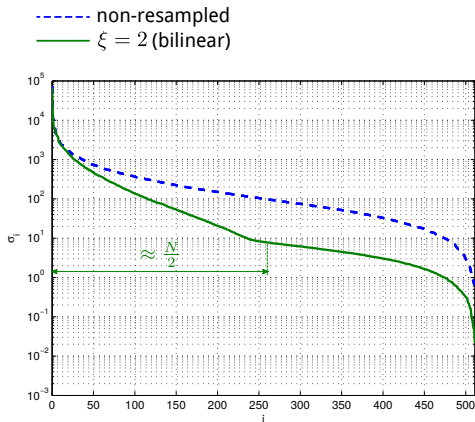


Non-resampled image



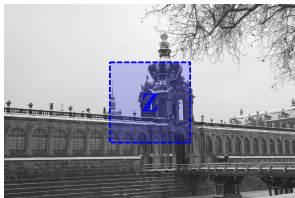
Quantized resampled image

Evolution of the singular values of Z :



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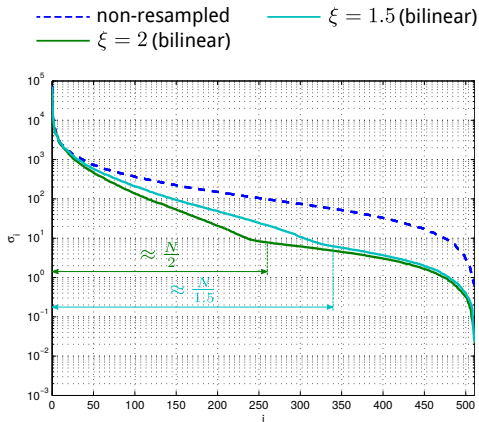


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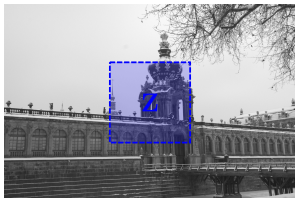
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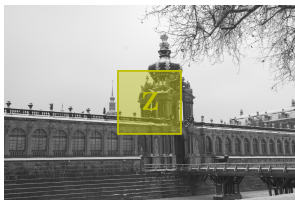


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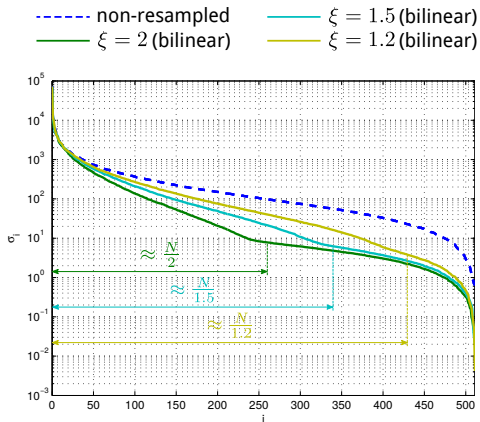


Non-resampled image



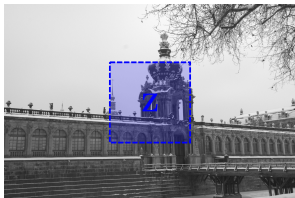
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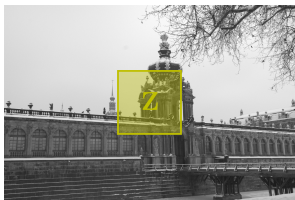


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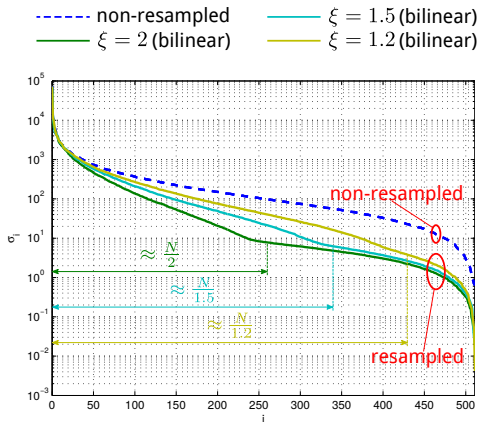


Non-resampled image



Quantized resampled image

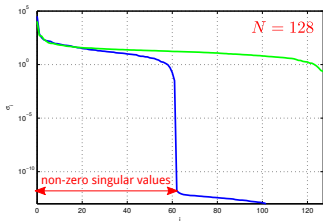
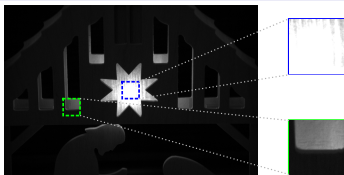
Evolution of the singular values of Z :



Saturation Problem

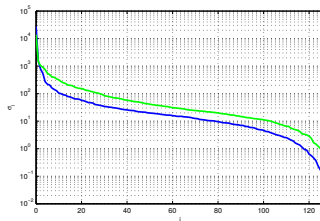
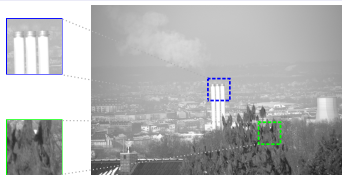
Case 1

The number of non-zero singular values is substantially smaller than N .



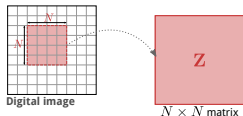
Case 2

The magnitude of the singular values vanishes more sharply than usual.



Proposed Detector for $\xi > 1$

Observed Data:



Hypothesis Test

- $\mathcal{H}_0$: Z has never been resampled.
- $\mathcal{H}_1$: Z has been resampled by any $\xi > 1$.

Test statistic: ρ

Will measure the magnitude of singular values at a certain index.

Degree of Saturation: s

■ $\gamma_{\text{row}} \triangleq \frac{\# \text{ saturated pixels in } Z}{\# \text{ rows}}$

■ $s \triangleq \frac{1}{N} \max \{ \gamma_{\text{row}}, \gamma_{\text{column}} \}$



$s = 0.8389$



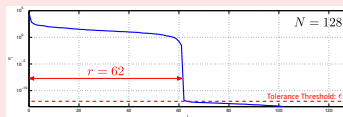
$s = 0.5272$



$s = 0.0344$

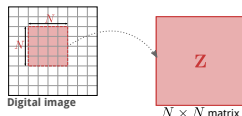
Non-zero Singular Values: r

■ $r \triangleq \# (\sigma_{\forall i} > \epsilon), \quad \epsilon = 2^{-52}$



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Hypothesis Test

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Test statistic: ρ

$$\rho \triangleq \begin{cases} 0, & \text{if } r < 0.1N, \\ \log(\sigma_{\nu - \lfloor 0.05N \rfloor}), & \text{if } s \geq 0.45 \text{ and } r > 0.95N, \\ \log(\sigma_{\nu-1}), & \text{otherwise.} \end{cases}$$

Selected index: ν

- Maximum number of significant dimensions achieved by any $\xi \geq \xi_{\min} \rightarrow \nu = \text{round}\left(\frac{r}{\xi_{\min}}\right)$.

Decision

$$\mathcal{H}_0 : \quad \rho > T,$$

$$\mathcal{H}_1 : \quad \rho \leq T.$$

Experimental Setup

Image Dataset

- 1317 images from the **Dresden Image Database** (Nikon cameras).

Full-frame resampling through `convert` from ImageMagick

- **Interpolation kernels:** *Bilinear*, *Catmull-Rom*, *B-spline*, *Lanczos*.
- **Set of resampling factors:** $\xi \in \{1.05, 1.1, \dots, 1.95, 2\}$, ($\xi_{\min} = 1.05$).

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Benchmark detector

- **Kirchner's detector:** based on row/column predictors ($K = 3$).

Resampling Analysis

- **Blocks of small size:** center 32×32 block of the green channel.

Experimental Setup

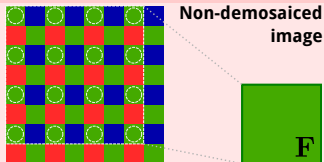
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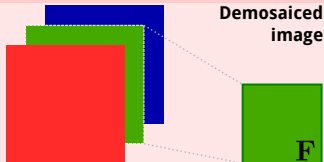
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1. Without demosaicing traces

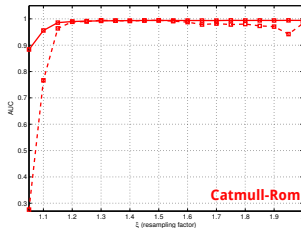
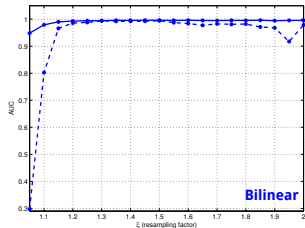


2. With demosaicing traces



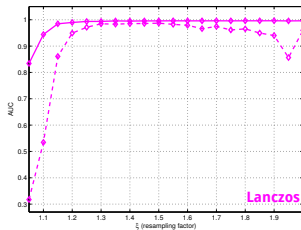
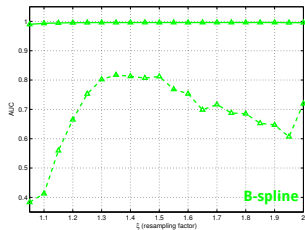
Experimental Results: without demosaicing traces

Area under the ROC curve (AUC):



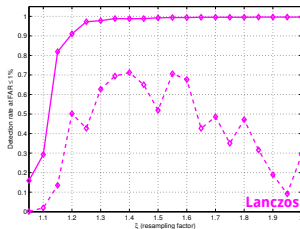
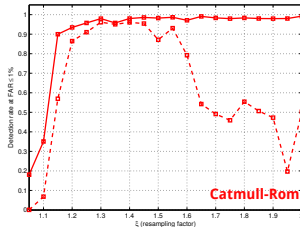
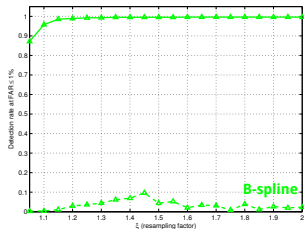
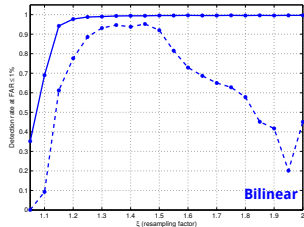
Detectors:

— SVD-based
- - - Kirchner



Experimental Results: without demosaicing traces

Detection rate at 1% False Alarm Rate:

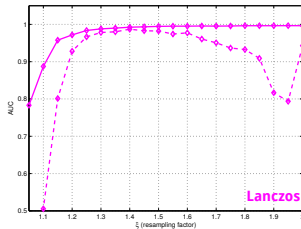
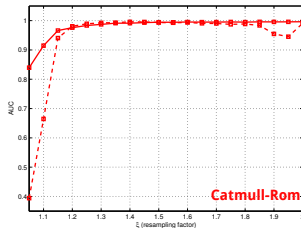
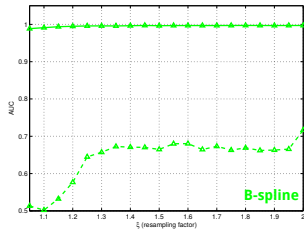
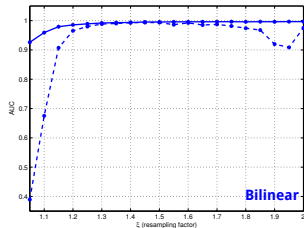


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Area under the ROC curve (AUC):

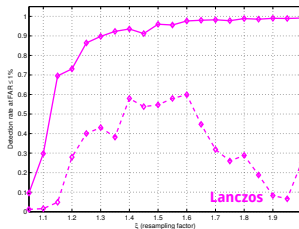
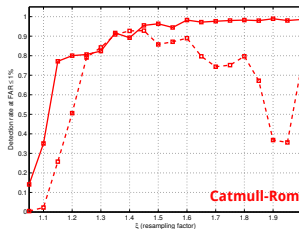
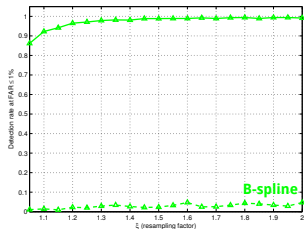
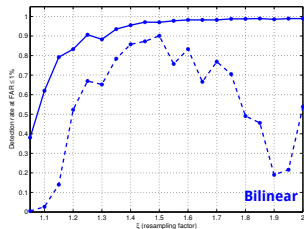


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Conclusions and Future Work

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- Subspace decomposition of resized images enables resampling detection.
- Proposed detector follows a simple strategy:
 - SVD of an image block.
 - Degree of pixel saturation.
- Promising results are obtained with blocks of small size.

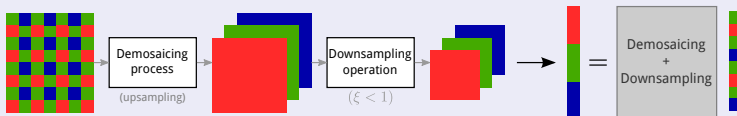
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Future Work

- Extension of the proposed approach for dealing with downsampling.



Thanks for your attention.

Questions?

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