* Pintura de Rajib Roy, Case Investigation - 2012

Digital Forensics

MO447 / MC919

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RECOD

Summary

- Steganography
  - LSB insertion/modification
  - FFTs and DCTs
- How to improve security

Summary

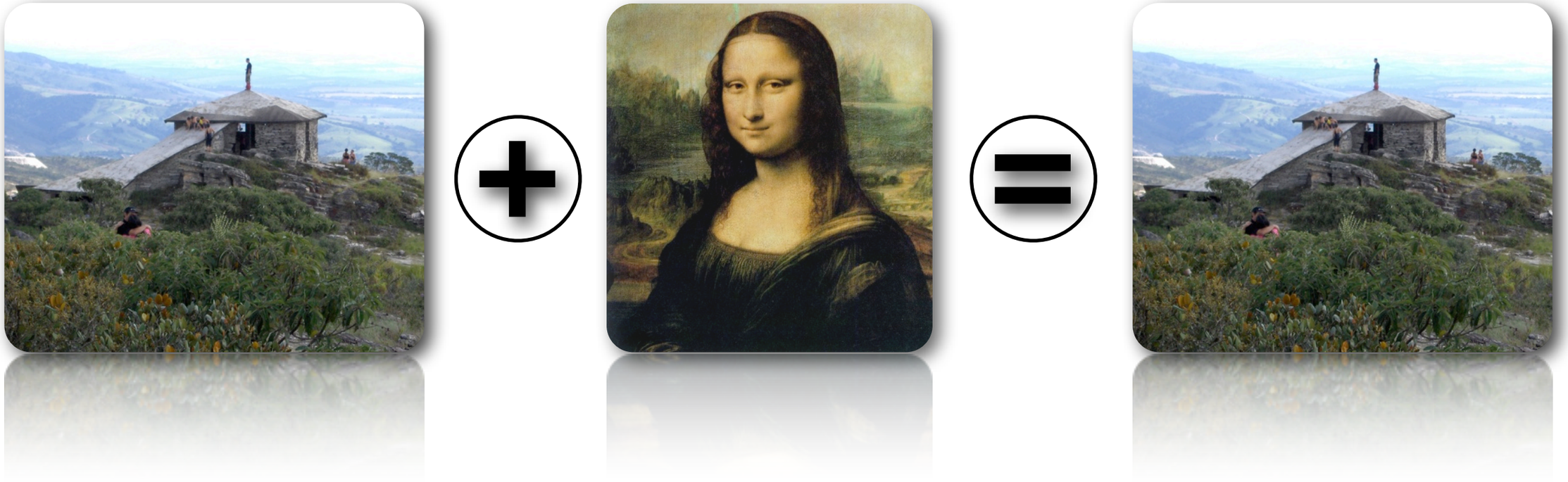
- Steganalysis
  - Aural
  - Structural
  - Statistical

Summary

- Freely available tools and software
- Open research topics
- Conclusions and remarks

Steganography

Hiding scenario



Steganography

- Computer Vision and Image Processing techniques
- Mostly based on replacing a noise component

Steganography

- What are the problems of noise embedding?
  - Compression
  - Filtering
  - Conversions
- MSB-based techniques

Steganography techniques

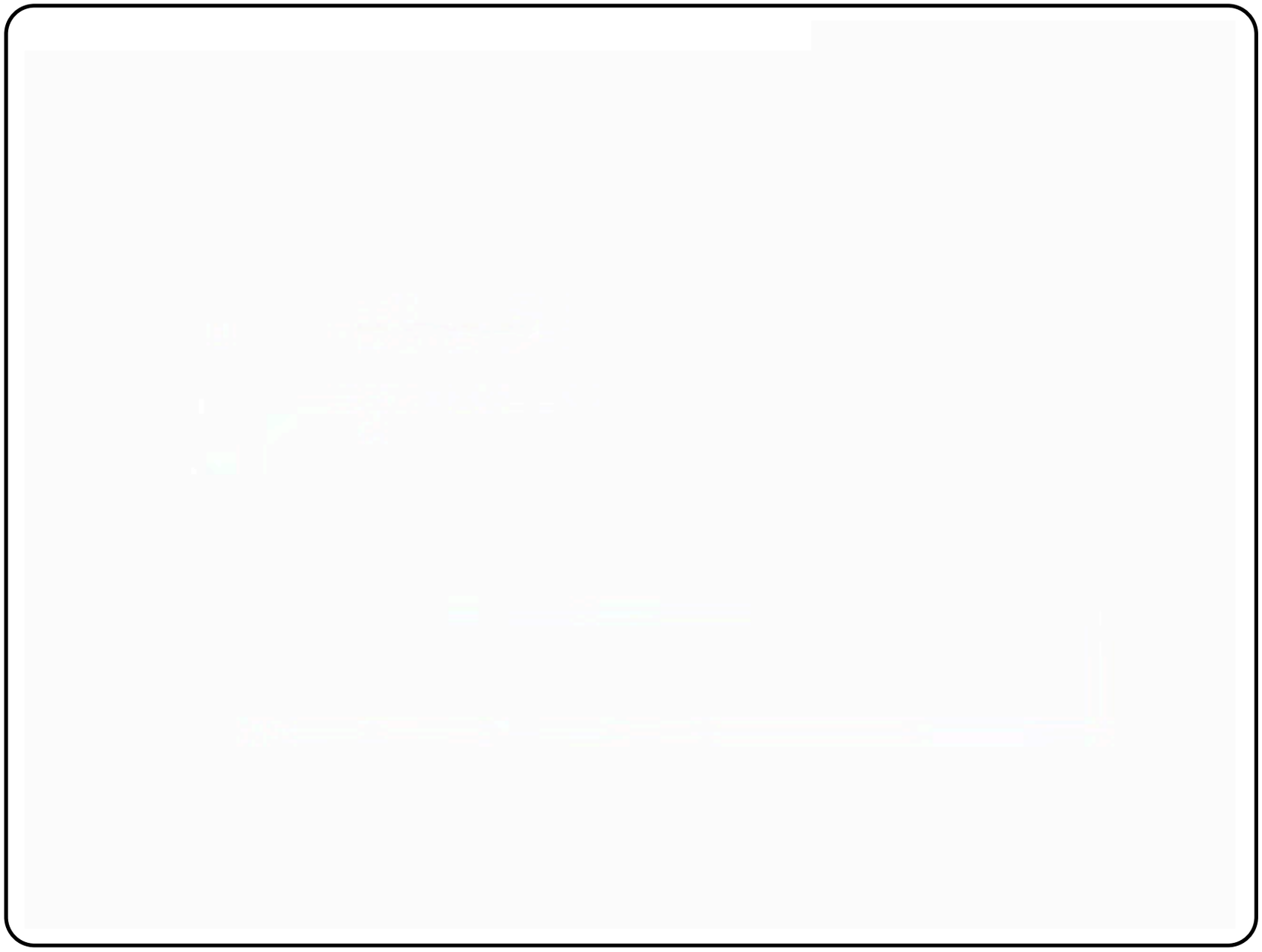
LSB insertion/modification

Extracting image's bit channels

Given a **24-bit typical** color image, we want to extract its 8 bit channels

Steganography techniques

LSB insertion/modification



Steganography techniques

FFTs and DCTs based

1. Least significant coefficients
   - JSteg and Outguess
2. Block tweaking
3. Coefficient selection
4. Wavelets

Steganography techniques

FFTs and DCTs based

1. Splitting. Split up the image into 8x8 blocks.
2. Transformation. Transform each block via a DCT/FFT.
3. Compression stage 1. Use a quantizer to round the coefficients.
4. Compression stage 2. Use a Huffman encoding scheme or similar to further compress the streamlined coefficients.
5. Decompressing. Use inverse DCT/FFT to decompress.

DCT and FFT general algorithm

Steganography techniques

FFTs and DCTs

- JSteg
  - Sequentially replaces LSB of DCT/FFT coefficients
  - Does not use shared key
  - What is its main problem?

Steganography techniques

FFTs and DCTs

```
Require: message M, cover image I;
 1: JSteg(M,I)
 2:   while M != NULL do
 3:     get next DCT coefficient from I
 4:     if DCT != 0 and DCT != 1 then
 5:       b = next bit from M
 6:       replace DCT LSB with message bit b
 7:       M = M - b
 8:     end if
 9:     Insert DCT into stego image S
10:   end while
11:   return S
12: end procedure
```

JSteg general algorithm

Steganography techniques

FFTs and DCTs

- Outguess
  - Improvement over JSteg
  - PRNG
  - Statistical profiling

Steganography techniques

FFTs and DCTs

```
Require: message M, cover image I, shared key k;
 1: Outguess(M,I, k)
 2: Initialize PRNG with the shared key k
 3:   while M != NULL do
 4:      get pseudo-random DCT coefficient from I
 5:      if DCT != 0 and DCT != 1 then
 6:         b = next bit from M
 7:         replace DCT LSB with message bit b
 8:         M = M - b
 9:      end if
10:      Insert DCT into stego image S
11:    end while
12:    return S
13: end procedure
```

Outguess general algorithm

Steganography techniques

FFTs and DCTs

2. Block tweaking
   - DCT/FFT's quantizer stage
   - Keeps down distortions
   - Vulnerable to noise
   - Low-capacity embedding

Steganography techniques

FFTs and DCTs

- Coefficient selection
  - Selects *k* largest DCT/FFT coefficients
  - Use a function *f* that considers the required strength of the embedding process

required strength

$$f(\gamma') = \gamma_i + \alpha b_i$$

b_i is the bit you want to embed in the coefficient

Steganography techniques

FFTs and DCTs

- Wavelets
  - DCT/FFT transformations are not effective at higher-compression levels
  - Possibility to embed in the high-frequency
  - Embedding in the quantization stage

Steganography techniques

How to improve security

- Kerckhoff's Principle
- Destruction of the original
- Statistical profiling

How to improve security

- Structural profiling
- Split the information
- Compaction

Steganalysis

Steganalysis

- Detection of hidden messages
- Early approaches focused on detection
- Next step: recovery

Steganalysis

- Steganalysis attacks

1. Aural
2. Structural
3. Statistical

Statistical Steganalysis

χ^2 Analysis

- An *L*-bit color channel represent 2^L possible values
- Split in 2^{L-1} pairs differing in the LSBs only
- All possible patterns of neighboring bits for the LSBs

$$PoV : 0 \leftrightarrow 1, 2 \leftrightarrow 3, \ldots, 254 \leftrightarrow 255$$

A. Westfeld and A. Pfitzmann. *Attacks on Steganographic Systems.* IHW 1999.

Statistical Steganalysis

χ^2 Analysis

- What if we use all available LSBs?
- Expected frequency *vs* observed one
- Expected frequency is not available
- In the original the EF is the arithmetical mean in each PoV

Statistical Steganalysis

χ^2 Analysis

- The embedding affects only the LSBs
- Arithmetical mean remains the same in each PoV
- χ^2 to detect hidden messages

$$\chi^2 = \sum_{i=1}^{\nu+1} \frac{(f_i^{obs} - f_i^{exp})^2}{f_i^{exp}}$$

Statistical Steganalysis

χ^2 Analysis

- Probability of hiding

$$ph = 1 - \int_0^{\chi^2} \frac{t^{(\nu-2)/2} e^{-t/2}}{2^{\nu/2}\Gamma(\nu/2)} dt$$

Statistical Steganalysis

χ^2 Analysis

- Only detects sequential messages
- The threshold value for detection may be quite distinct for different images
- Low-order statistics

Statistical Steganalysis

RS Analysis (RS)

- Analysis of the LSB loss-less embedding capacity
- The LSB plane is correlated with other bit planes
- Simulates artificial new embeddings

J. Fridrich, M. Goljan, and R. Du. *Detecting LSB Steganography in Color and Grayscale Images*. IEEE Multimedia, vol. 8, n. 4, pp. 22-28, 2001.

Statistical Steganalysis

RS Analysis (RS)

- Let *I* be the image with WxH pixels
- Pixel values in P = {1...255}
- Divide *I* in G disjoint groups of *n* adjacent pixels (e.g., n = 4)

Statistical Steganalysis

RS Analysis (RS)

- Define a discriminant function to classify the G groups

$$f(x_1, \ldots, x_n) = \sum_{i=1}^{n-1} |x_{i+1} - x_i|$$

Statistical Steganalysis

RS Analysis (RS)

- Flipping invertible function

$$F_1 : 0 \leftrightarrow 1, 2 \leftrightarrow 3, \ldots, 254 \leftrightarrow 255$$

- Shifting invertible function

$$F_{-1} : -1 \leftrightarrow 0, 1 \leftrightarrow 2, \ldots, 255 \leftrightarrow 256$$

- Identity function

$$F_0(x) : x \forall\ x \in P$$

Statistical Steganalysis

RS Analysis (RS)

- Define a mask M = {-1,0,1}
- The mask defines which function to apply
- The mask's compliment is -M

Statistical Steganalysis

RS Analysis (RS)

- Apply the functions over the groups for M and -M masks. Classify them as
  - Regular. $G \in R_{\mathcal{M}} \Leftrightarrow f(F_{\mathcal{M}}(G)) > f(G)$
  - Singular. $G \in S_{\mathcal{M}} \Leftrightarrow f(F_{\mathcal{M}}(G)) < f(G)$
  - Unusable. $G \in U_{\mathcal{M}} \Leftrightarrow f(F_{\mathcal{M}}(G)) = f(G)$

Statistical Steganalysis

RS Analysis (RS)

- It holds that

$$\frac{R_{\mathcal{M}} + S_{\mathcal{M}}}{T} \leq 1 \text{ and } \frac{R_{-\mathcal{M}} + S_{-\mathcal{M}}}{T} \leq 1,$$

- Statistical hypothesis

$$R_{\mathcal{M}} \approx R_{-\mathcal{M}} \text{ and } S_{\mathcal{M}} \approx S_{-\mathcal{M}}$$

Gradient Energy Flipping Rate (GEFR)

- Gradient of an unidimensional signal

$$r(n) = I(n) - I(n-1)$$

- The I(n)'s GE is

$$GE = \sum |I(n) - I(n-1)|^2 = \sum r(n)^2$$

L. Zhi, S. Fen, and Y. Xian. *An LSB Steganography detection algorithm*. Intl. Symposium on Personal, Indoor, Mobile Radio Communication, 2003

Gradient Energy Flipping Rate (GEFR)

- After hiding a signal S(n) in the original signal, I(n) becomes I'(n) and the gradient becomes

$$
\begin{aligned}
r(n) &= I(n) - I(n-1) \\
&= (I(n) + S(n)) - (I(n-1) + S(n-1)) \\
&= r(n) + S(n) - S(n-1)
\end{aligned}
$$

Gradient Energy Flipping Rate (GEFR)

- After any kind of embedding GE' becomes

$$GE' = \sum |r(n) + \Delta(n)|^2$$

$$\text{where } \Delta(n) = S(n) - S(n-1)$$

Statistical Steganalysis

Gradient Energy Flipping Rate (GEFR)

- To perform the detection, define a function to simulate new embeddings

Gradient Energy Flipping Rate (GEFR)

1. Find the test image's $GE\left(\frac{p/2}{W \times H}\right)$
2. Apply F over the test image and calculate $GE\left(\frac{W \times H - p/2}{W \times H}\right)$
3. Find $GE\left(\frac{W \times H}{2}\right) = \left[EG\left(\frac{p/2}{W \times H}\right) + GE\left(\frac{W \times H - p/2}{W \times H}\right)\right]/2$
4. GE(0) is based on $GE\left(\frac{W \times H}{2}\right) = GE(0) + W \times H$
5. Find the message's estimated size $p' = GE\left(\frac{p/2}{W \times H}\right) - GE(0)$

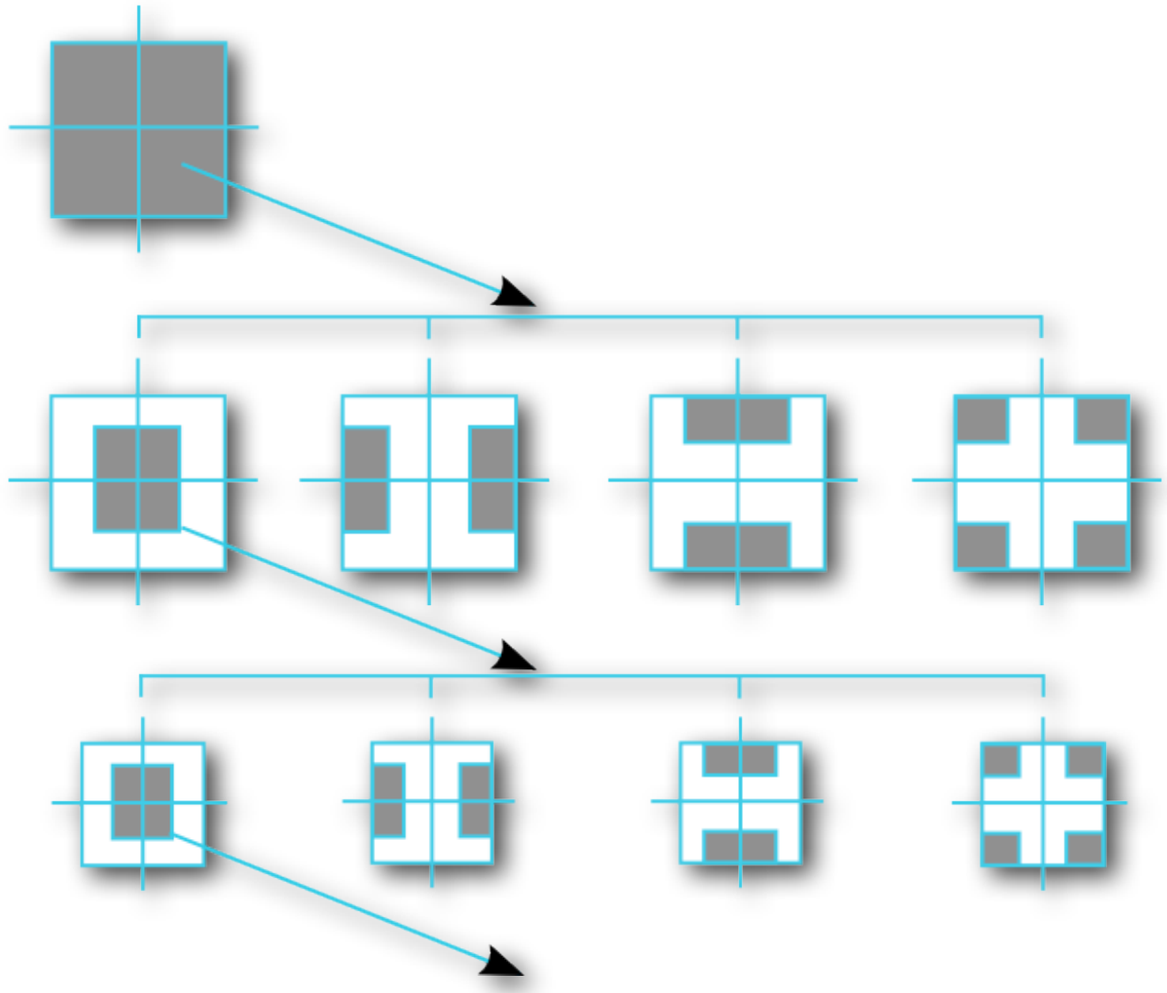
GEFR general algorithm

High-order Statistical analysis

- Natural images have regularities
- They can be detected with high-order statistics
- Use QMF decomposition for multi-scale analysis

S. Lyu and H. Farid. *Detecting Hidden Messages Using Higher-order Statistics and Support Vector Machines*. IHW 2002.

High-order Statistical analysis



QMF decomposition

High-order Statistical analysis

- Let $V_i(x,y)$, $H_i(x,y)$, and $D_i(x,y)$ be the vertical, horizontal, and diagonal sub-bands for a given scale $i = \{1,...n\}$
- Statistical model composed by Mean, Variance, Skewness, and Kurtosis
- Basic coefficients distribution

Statistical Steganalysis

High-order Statistical analysis

- Second set of statistics
  - Errors on an optimal linear predictor of coefficient magnitude
  - Spatial, orientation, and scale neighborhood

High-order Statistical analysis

- For instance: errors for all neighbors in the vertical sub-band at scale *i*

$$V_i(x,y) = w_1 V_i(x-1,y) + w_2 V_i(x+1,y) + w_3 V_i(x,y-1) +$$
$$w_4 V_i(x,y+1) + w_5 V_{i+1}(\frac{x}{2},\frac{y}{2}) + w_6 D_i(x,y) + w_7 D_{i+1}(\frac{x}{2},\frac{y}{2})$$

- w_k denotes scalar weighting values

High-order Statistical analysis

- Quadratic minimization of the error function

$$E(w) = [V - Qw]^2$$

- V is a column vector of magnitude coefficients
- Q is the magnitude neighbors' coefficients

High-order Statistical analysis

- Minimization through differentiation wrt *w*

$$\frac{dE(w)}{dw} = 2Q^T[V - Qw]$$

- Calculate w_k using the linear predictor log error

$$log_2(V) - log_2(|Qw|)$$

Statistical Steganalysis

High-order Statistical analysis

- 12(*n*-1) basic statistics
- 12(*n*-1) error statistics
- 24(*n*-1) feature vector

Statistical Steganalysis

High-order Statistical analysis

- Supervised learning
- Training set of stego and clean images
- LDA and SVMs

Image Quality Metrics (IQMs)

- Often used for
  - Coding artifact evaluation
  - Performance prediction of vision algorithms
  - Quality loss due to sensor inadequacy

I. Avcibas, N. Memon, B. Sankur. *Steganalysis using image quality metrics*. TIP vol. 12, n. 2, pp. 221-229, 2003.

Statistical Steganalysis

Image Quality Metrics (IQMs)

- IQMs
- Multivariate regression analysis (ANOVA)
- Exploits Steganographic schemes artifacts

Image Quality Metrics (IQMs)

- IQMs

1. Mean absolute error
2. Czekznowski correlation
3. Image fidelity
4. HVS error
5. etc

Image Quality Metrics (IQMs)

- Training set of stego and clean images
- ANOVA

$$\begin{cases} y_1 &= \beta_1 x_{11} + \beta_2 x_{12} + \ldots + \beta_q x_{1q} + \epsilon_1 \\ y_2 &= \beta_2 x_{21} + \beta_2 x_{22} + \ldots + \beta_q x_{2q} + \epsilon_2 \\ & \vdots \\ y_N &= \beta_n x_{n1} + \beta_2 x_{12} + \ldots + \beta_q x_{nq} + \epsilon_n, \end{cases}$$

Progressive Randomization (PR)

- It captures the differences between image classes
- Statistical artifacts inserted during the hiding process

A. Rocha and S. Goldenstein. *Progressive Randomization for Steganalysis*. IEEE MMSP, 2006.

Progressive Randomization (PR)

- Four stages
  1. Randomization process
  2. Feature regions selection
  3. Statistical descriptors analysis
  4. Invariance

Statistical Steganalysis

Progressive Randomization (PR)

- The idea behind PR
- Let X be a Bernoulli RV
- Transformation T(l,p)

L(pxi) = pixel's LSB
bi = bit to be hidden
S = Random set of pixels
p = percentage of S

$$\mathcal{L}(px_i) \leftarrow b_i \forall\ px_i \in S$$

Progressive Randomization (PR)

Require: Input image *I*; Percentage P = {P_i, ... ,P_n};

1: Randomization: perform *n* LSB pixel disturbances on *I*

$$\{O_i\}_{i=0\ldots n.} = \{I, T(I, P_1), \ldots, T(I, P_n)\}$$

2: Region selection: select *r* feature regions of each image $i \in \{O_i\}_{i=0\ldots n}$

$$\{O_{ij}\}_{\substack{i=0\ldots n,\\ j=1\ldots r.}} = \{O_{01}, \ldots, O_{nr}\}.$$

3: Statistical descriptors: calculate *m* descriptors for each region

$$\{d_{ijk}\} = \{d_k(O_{ij})\}_{\substack{i=0\ldots n,\\ j=1\ldots r,\\ k=1\ldots m.}}$$

4: Invariance: normalize the descriptors based on *I*

$$F = \{f_e\}_{e=1\ldots n\times r\times m} = \left\{\frac{d_{ijk}}{d_{0jk}}\right\}_{\substack{i=0\ldots n,\\ j=1\ldots r,\\ k=1\ldots m.}}$$

Progressive Randomization algorithm

Statistical Steganalysis

Progressive Randomization (PR)

- Randomization stage
  - It simulates new embeddings
  - $n = 6$
  - P = {*1%,5%,10%,25%,50%,75%*} of the LSBs

Progressive Randomization (PR)

- Statistical descriptors stage
  - χ^2
  - Ueli Maurer that measures randomness

Progressive Randomization (PR)

Statistical Steganalysis

Progressive Randomization (PR)

- Invariance stage
  - The variation rate is more interesting
  - Normalize all transformation's result ($T_1 ... T_n$) wrt. T_0

Statistical Steganalysis

Progressive Randomization (PR)

- Classification stage
  - Training set of stego and clean images
  - Supervised learning
  - |M| = 25% (~13% changed LSBs) > 90% accuracy (SVMs)

Progressive Randomization (PR)

Progressive Randomization

Normalizing the feature vector

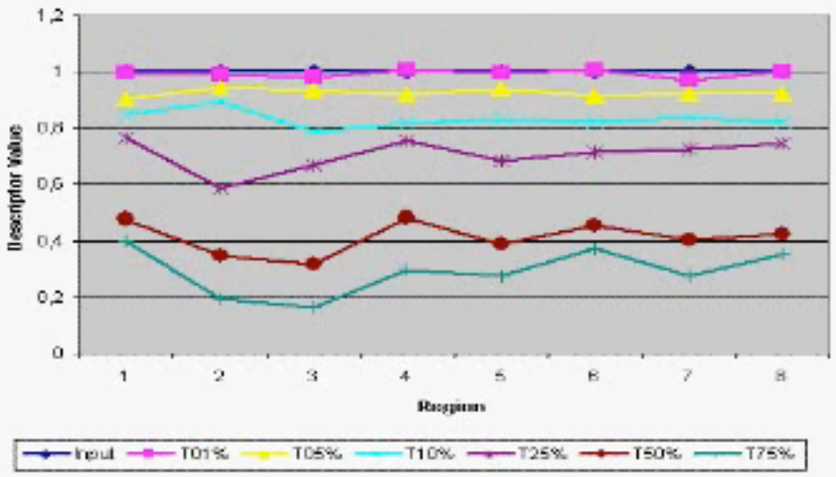
We use **six** progressive randomization steps;

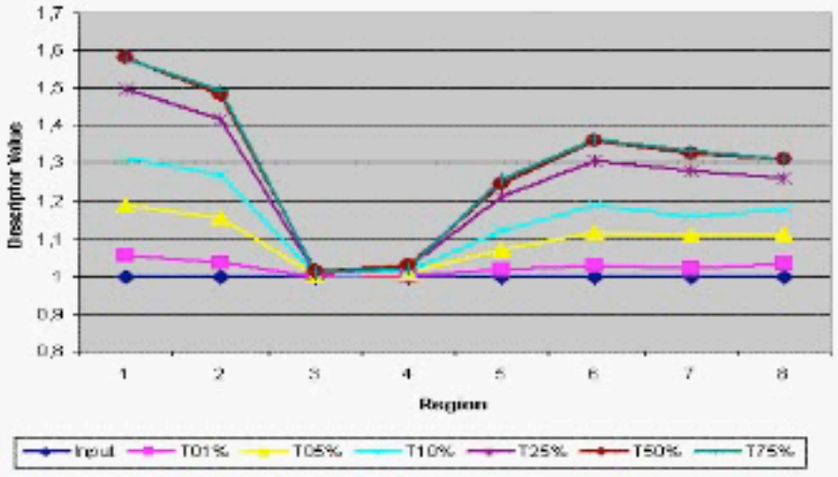
We **normalize** the descriptors' values of each stage by their value in the original image

$$Norm(O_i) = d_j(O_i)/d_j(I),$$

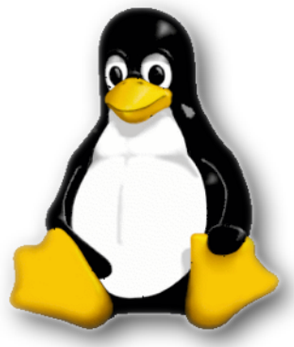
where O_i refers to the i^{th} output of the **Progressive Randomization Stage.**

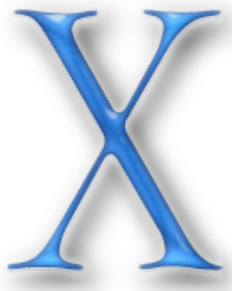
We have a **96-dimensional** feature space





Software and tools





Software and tools

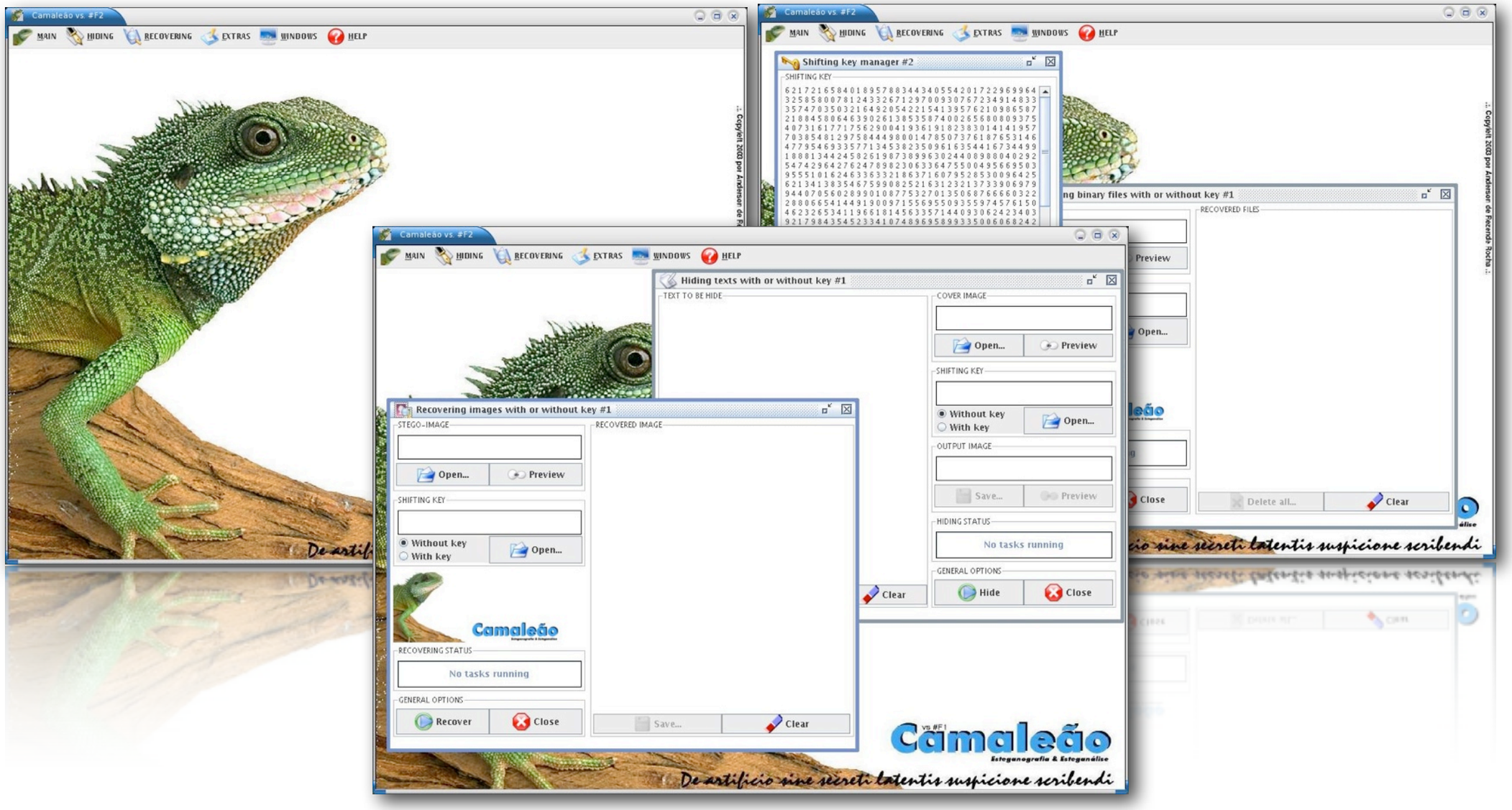
- EzStego
- Stego Online
- Mandelsteg
- Stealth

Software and tools

- White Noise
- S-Tools
- Hide and Seek
- JSteg
- Outguess

Software and Tools

Camaleão



www.ic.unicamp.br/~rocha/sci/stego

Interesting research topics

Open research topics

- Images are subjected to many operations
  - Translation, rotation, shear
  - Blurring, filtering, lossy compression
  - Printing, rescanning, conversion

Open research topics

- Designing of robust IH techniques
  - Robustness to geometrical attacks
  - Embeddings in regions with richness of details

Open research topics

- Good IQMs
- Public key systems
- Multiple embeddings with no interference

Open research topics

- Blind detection
- Very small embedding detection
- Adaptive techniques
- Hidden content recovery

Conclusions

Conclusions

- Steganography and Steganalysis overview
- IH embedding and detection techniques
- Open research topics

Conclusions

- Data hiding has passed its period of hype
- Public fear created by mainstream press reports
- Laws against IH techniques dissemination

Conclusions

- Nowadays...
  - Steganography and Steganalysis are mature disciplines
  - Applications
  - Research opportunities

Conclusions

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GO

Hello Kitty was drug lord's messenger

Article from: Agence France-Presse

Font size: Email article: Print article:

March 11, 2008 03:54am

HELLO Kitty, the Japanese cartoon figure popular with teenagers around the world, was used by a notorious Colombian drug lord to hide messenges to his minions.

Juan Carlos Ramirez Abadia, who is being held in Brazil after his arrest in August, hid voice and text messages digitally encoded into emailed images of the innocent feline, Brazilian police told the *Folha de Sao Paulo* newspaper.

Investigators say the disguised missives, hundreds of which were found on Abadia's computer, could put the narcotics kingpin up to his neck in Kitty litter as some of them allegedly detail cocaine shipments between countries.

...

Also in Breaking News

- **'Abuse'** : Ex-cult members speak out over church
- **Harare:** Tsvangirai withdraws from election
- **London:** Winehouse diagnosed with emphysema
- **Iloilo:** 229 dead in typhoon
- **Internet:** Man auctioning his 'life' celebrates
- **Cold cases:** Appeal for leads on unsolved murders
- **Nielsen speaks:** Carey 'pushed but never punched'
- **Harare:** Mugabe's men disrupt opposition rally
- **Rome:** Berlusconi 'fears prison sentence'
- **Manila:** Typhoon death toll 155 - Red Cross
- **House fire:** Woman attacked by dog during 'domestic'
- **Operation over:** Last troops return from Iraq

Steg in real world

Thank You!

Obrigado!