Image Forensics and Steganalysis

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26 June 2009

1. Examples
   - Tampering
   - Different Security Scenarioes
2. Steganography and Steganalysis
   - Steganography
   - JPEG and F5
   - The Markov Based Model
   - Double Compression
   - Conditional Probability Features
3. Our group
4. Conclusion

Outline

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How worrying is the Iranian weaponry?

- Picture from AFP.
- One of the rockets really fired
- Some rockets are the product of PhotoShop...
- The image was retracted after publication

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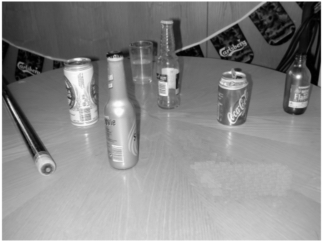
Crime Scene Photography

- What did the crime scene look like?
  - Photography is vital evidence
- Photography can be altered...
  - What can we prove?

Crime Scene Photography



- What did the crime scene look like?
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Who were actually there?

- Former Culture Secretary James Purnell
- Late for the meeting.
  - Arrived after three other MPs had to leave.
- James Purnell was added to the picture
- (BBC News - 28 September 2007)

Outline

Is the photo real?

- Does it show reality?
- Or has its author exercises artistic licence?
  - tampering with evidence
  - adding grandeur to a story
  - computer generated images
- For example
  - Merging images
  - Erasing details or objects

Where does the photo come from?

- Objective: add credibility to claims
- All information about the image is potentially useful...
- Which camera took the image?
- Time of day, time of year, etc.
- Subsequent image processing
  - contrast, compression, brightness, etc.

Where does the photo come from?

- Objective: add credibility to claims
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Is there more than meets the eye?

- Additional information hidden in the image?
  - known as *steganography*

Three important questions

1. Is the photo real?
2. Where does the photo come from?
3. Is there more than meets the eye?

User scenarios

- News agency, news paper, etc.
  - can we trust images from the public?
  - they can get thousands of images in a day
- Forensics and Court of Law
  - what can we prove?
  - what is the truth?
  - is the image real or synthetic?
- Intelligence services
  - is there secret communications hidden in the image?

Outline

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The basic problem

Simmons Crypto'83

Alice

Bob

The basic problem

Simmons Crypto'83

Alice

Bob

William the Warden

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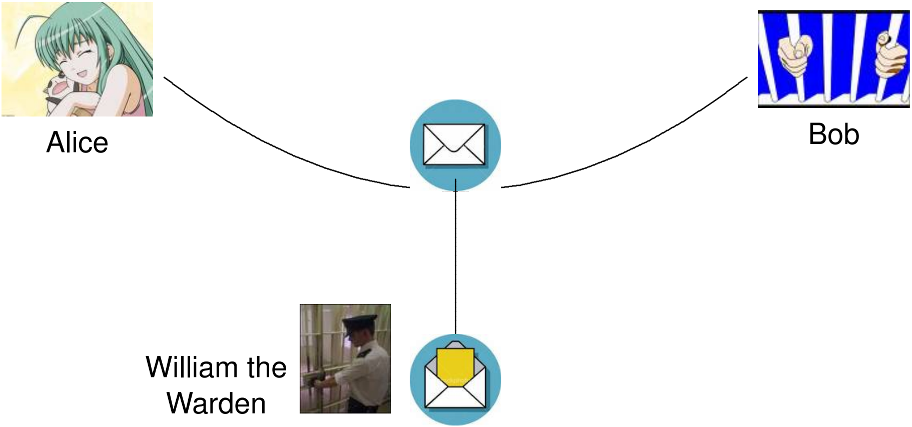
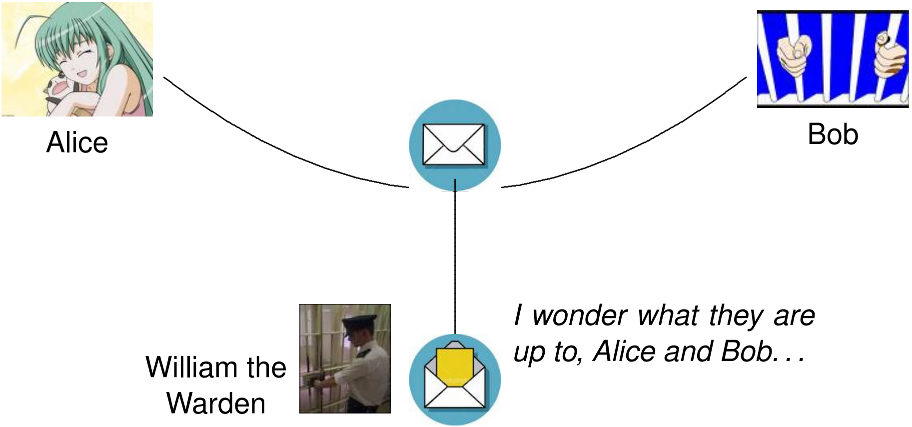
The basic problem

Simmons Crypto’83



The basic problem

Simmons Crypto’83



The basic problem

Simmons Crypto'83

Alice

About Uncle Charlie who is ill.

Bob

William the Warden

Family matters. None of my business.

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The basic problem

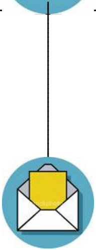
Simmons Crypto’83

Alice

Discussing escape plans.

Bob

William the Warden



Oh dear. That’s maximum security for Bob.

The basic problem

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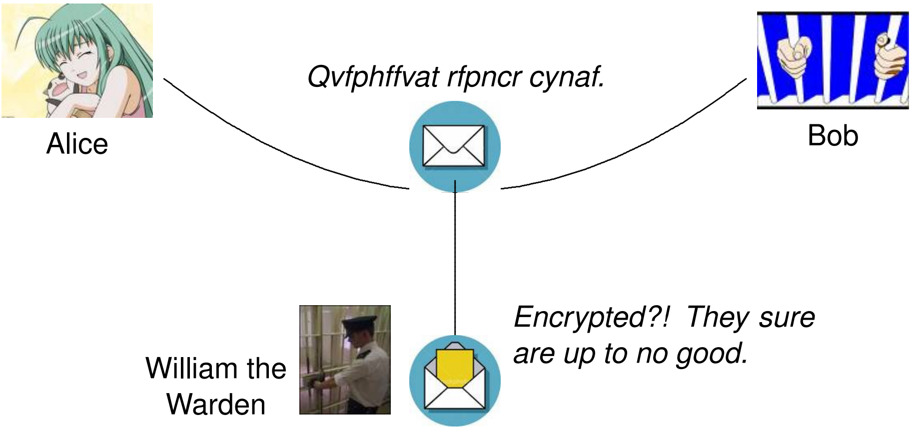
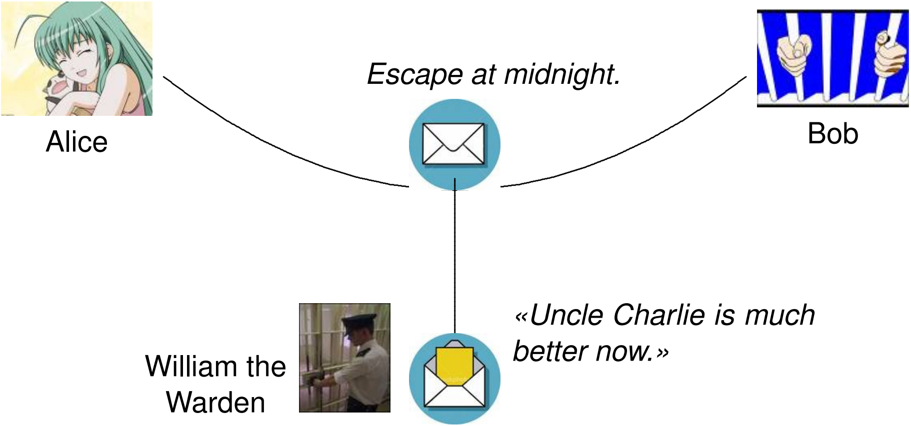


The vision

Simmons Crypto'83



The basic crypto-problem

Encryption

Alice

Bob the Banker

The basic crypto-problem

Encryption

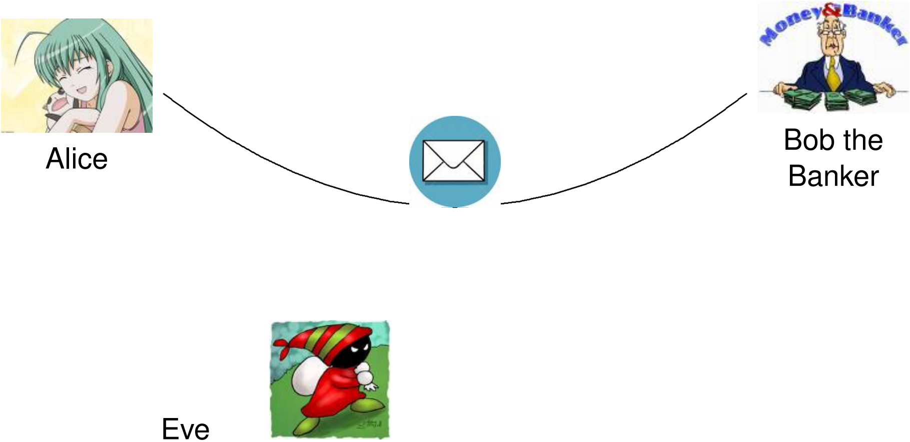
Alice

Bob the Banker

Eve

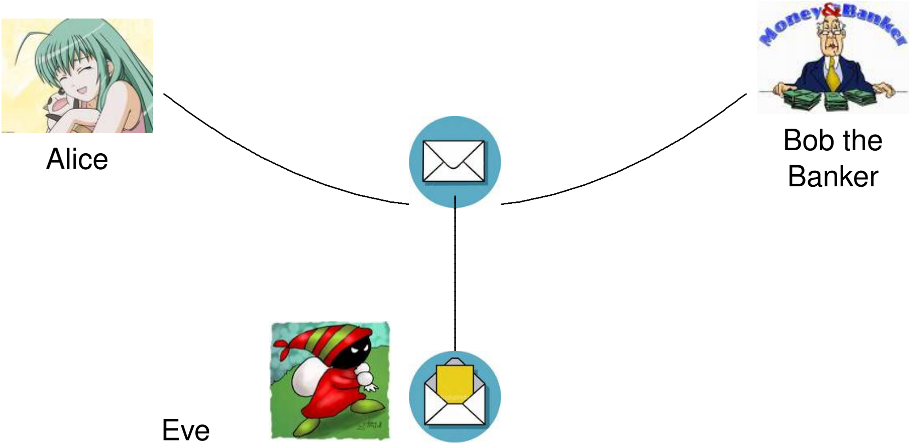
The basic crypto-problem

Encryption



The basic crypto-problem

Encryption



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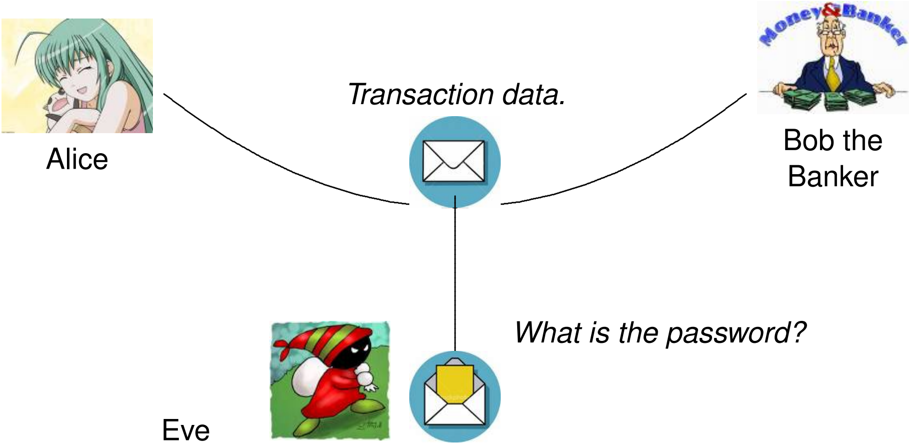
Encryption



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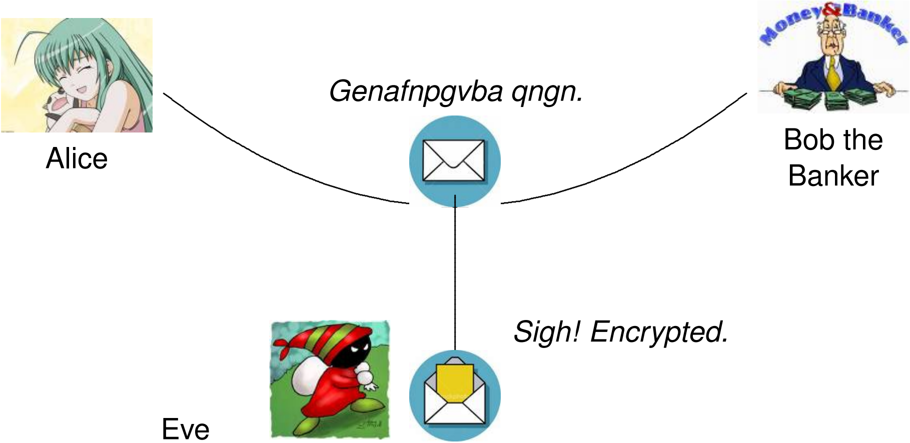


The data hiding system

The pure stego-system

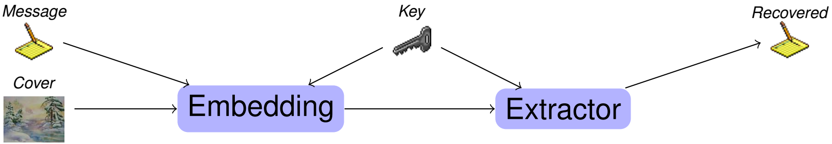
The data hiding system

The pure stego-system

- Security depends on the confidentiality of the algorithm.

The data hiding system

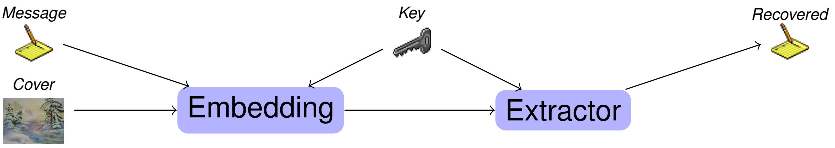
Secret-key stego-system



- The key k is shared confidentially by Alice and Bob.
  - Gives Bob an edge over Eve.
- Without the key, the stego-text is indistinguishable from any other cover text

The data hiding system

Secret-key stego-system



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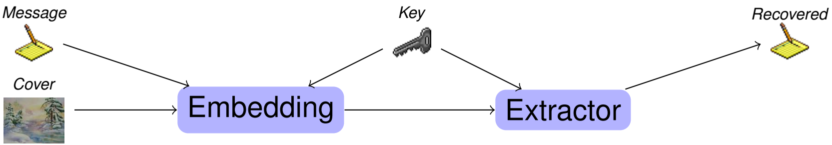

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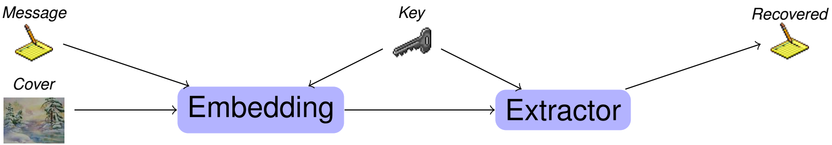
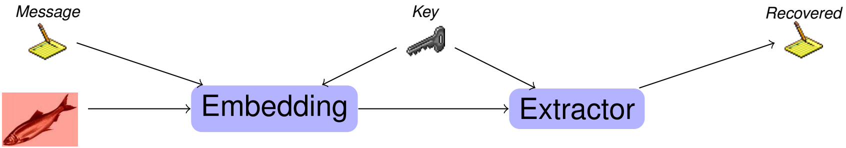


- The cover text is a red herring
- It has no value at the receiver

The data hiding system

Significance of the Cover Image



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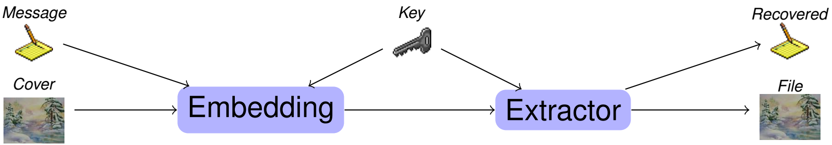
The data hiding system

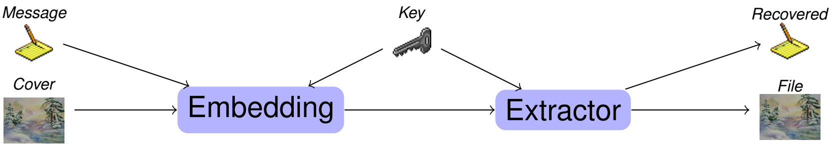
Watermarking System



- Related to watermarking – where the cover image is essential.
- Watermarking ties the message to the cover.
  - The attacker tries to separate the two.

The data hiding system

Watermarking System



The data hiding system

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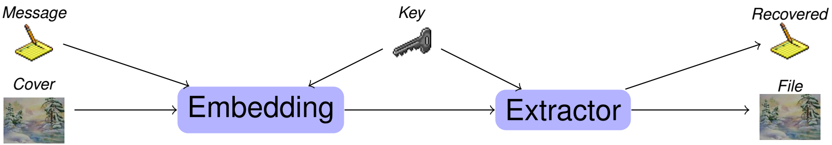

Definitions

The tools

Definition (Stego-system)

A system which allows Alice and Bob to communicate secretly without Eve knowing that any secret communication is taking place.

Definition (Steganography)

The study of (and art of developing) stego-systems.

Definition (Steganalysis)

The art of detecting whether secret communications is taking place or not.

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Steganalysis

Using Machine Learning

- Most recent steganalysis systems use Machine Learning
  - or related statistical techniques
- Most often a two-class SVM is used (natural vs. steganogram)

1. Extract features (statistics) from the image
   - Multi-dimensional floating point vector
2. Train the system
   - Input two ensembles of feature vectors
   - The system will estimate a model
3. Testing
   - Input the estimated model + Images from each class
   - Output classification decisions – Estimate accuracy
4. Real use
   - Input: model; feature vector from a suspicious image

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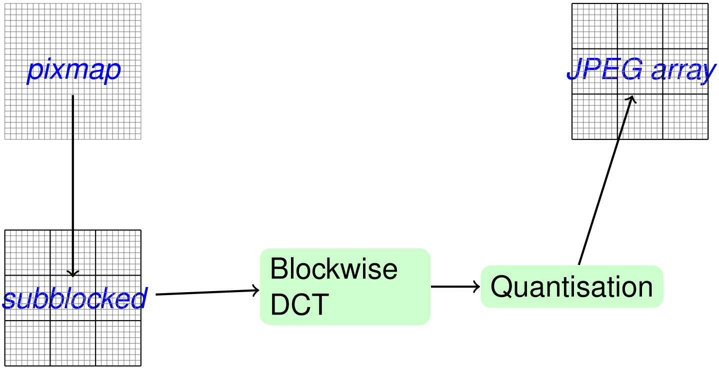
JPEG images



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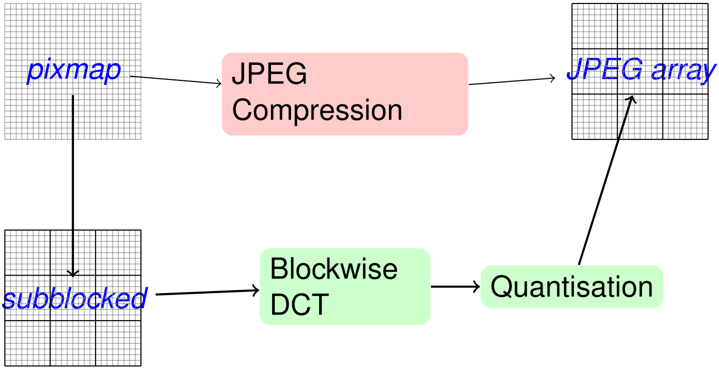
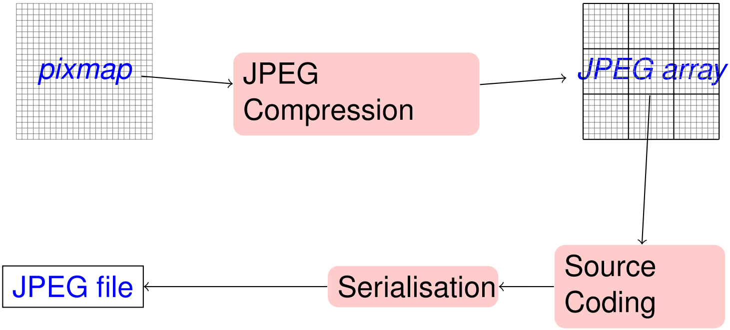

pixmap
JPEG Compression
JPEG array
subblocked
Blockwise DCT
Quantisation

JPEG images


pixmap
JPEG Compression
JPEG array
Source Coding
Serialisation
JPEG file

JPEG Steganography

- Many stego-algorithms work on the JPEG Array
  - Integer matrix
- E.g. Jsteg
  - Ignore $+1$ and 0 coefficients
  - Embed in the least significant bit of each coefficient
  - Extract by taking $c \mod 2$

The F5 Algorithm

by Andrea Westfeld

- Better preservation of image statistics
- JPEG coefficient magnitudes are always decreased
- Matrix coding (source coding) is used
  - coding to match the cover
  - minimise the number of modifications

Typical JPEG Steganography

- Modulate information on the cover
  - ± 1 changes to coefficients
- Independent modifications
  - Independence of the cover
  - Independence of individual coefficients
- This is the problem of steganography
  - Image coefficients are *not* independent
  - The modifications become detectible noise

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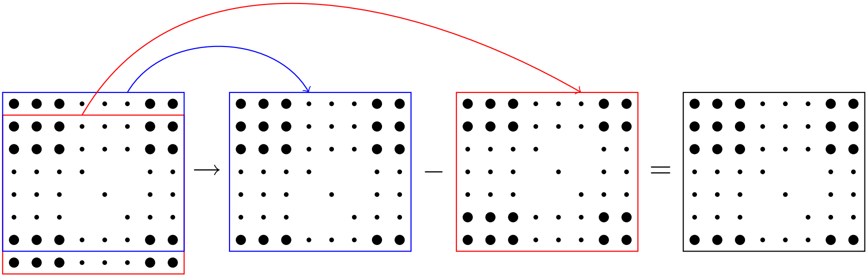
The Markov Based Model – Overview

Yun Q Shi *et al*

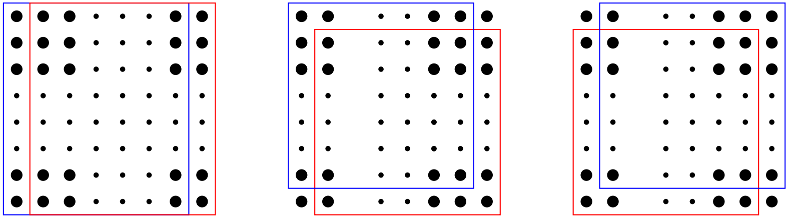
- Consider the absolute value of the JPEG array
- Difference matrix – differences between adjacent coefficients
- Model the difference matrix
  - First-order Markov model
- Estimate a Transition Probability Matrix
  - which forms our features

The difference array



- $F_v(i,j) = |J_{i,j}| - |F_{i+1,j}|$
- To reduce complexity, the difference array is capped at $\pm T$
  - Large (small) values are reduced (increased) to the capping value.

The other three difference arrays



- Horizontal, and major and minor diagonal

Transition Probability Matrix

- For $s, t \in \{-T, -T+1, \ldots, T-1, T\}$, we estimate
  - $M^v_{s,t} = P(F_v(i+1,j) = s | F_v(i,j))$
  - $M^h_{s,t} = P(F_h(i,j+1) = s | F_h(i,j))$
  - $M^d_{s,t} = P(F_d(i+1,j+1) = s | F_d(i,j))$
  - $M^m_{s,t} = P(F_m(i,j+1) = s | F_m(i+1,j))$
- This gives four matrices
  - $M^x = [M^x_{s,t}]$
- $4(2T+1)^2$ features
  - Shi *et al* suggested $T = 4$ for 323 features
- Performance around 90%–98% accuracy

Outline

The F5 implementation

- JPEG based stego-algorithms should work on the JPEG array
- This is what F5 (and Jsteg) Software actually do:

1. Load and Decompress the Image
   - Internal Spatial Representation
   - Compression Parameters are discarded
2. Compression and Embedding as an integrated process
   - Compression implemented by tweeking existing compression routines
   - Usually using default parameters
3. Save the comressed image

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Double Compression

- The F5 software recompresses the image
  - Usually using a different compression factor
  - Known as *Double Compression*
- This normally causes artifacts
- Typical Steganalysis classifiers
  - Compare Clean images against F5 processed images
  - What is detected?
  - Double Compression or Steganography?

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Alternative Experiment

- New training set
  1. Steganograms from F5 (with a hidden message)
  2. Cover images processed by F5 without a message
- Thus both of classes are doubly compressed
- Our classifier will have to work on the embedding only

1st vs. 2nd Order Markov Models

Performance

- Ignoring Double Compression

	Message length (bytes)		
	618	1848	4096
1st Order	89.5%	93.5%	98.0%
2nd Order	99.1%	99.1%	98.6%

- F5 vs. doubly compressed (clean) images

	Message length (bytes)		
	618	1848	4096
1st Order	50.2%	84.3%	97.9%
2nd Order	50.0%	55.6%	70.6%

1st vs. 2nd Order Markov Models

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Complexity

- Shi *et al*'s technique uses 323 features
- Computationally costly, to extract and to train
- We have proposed a simpler set
    - achieving similar performance

Basic ideas

1. The Markov Model is flawed
   - probability distribution of each coefficient is
     - determined by preceeding coefficients
     - independent of position
   - it should depend on the frequency (position in a subblock)
2. The transition probability matrix is too fine-grained
   - too many features to compute

The coefficients considered

	x_h	y_h	z_h				
x_v	x_d						
y_v		y_d					
z_v			z_d				

The CP Features

Definitions

- Triplet (x, y, z) as in figure
- Three posterior events
  - $A_1 : y > z$; $A_2 : y = z$; $A_3 : y < z$
- Three prior events
  - $B_1 : x > y$; $B_2 : x = y$; $B_3 : x < y$
- Nine features per triplet (x, y, z)
  - $P(A_i|B_j)$ fro $i, j = 1, 2, 3$
- 27 features in total
  - A 54-feature variant (six triplets) was less effective

Performance

CP Features

- Computation – Markov Model based technique in parenthesis
  - Training 770ms (150ms) on 2480 images
  - Classification 0.2ms (same) per image
  - Feature Extraction 114ms (13s) per image
- Accuracy (large message, 4kB)
  - 97.2% for both CP and Markov Model
  - 95% confidence interval is $(95.3\%, 99.2\%)$

Performance

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Steganalysis and Image Forensics
and Machine Learning

- Steganalysis
  - Development of Scientific Methodology
  - New feature sets
- sister team on Image Forensics
- sister group in Biologically Inspired Methods

Coding Theory

Applications in Data Hiding

- Deletion/Insertion Correction
  - for use in Watermarking
  - Geometric Distortions
- Wet Paper and Dirty Paper Coding
  - Distortion Minimisation in Watermarking and Steganography
- Construction/Non-Existence of Codes

Information Security

- Security in Contact-Less Payment Systems
  - are they sufficiently secure
- sister group in E-voting

Outline

Next project

- Information Forensics is a booming area
  - Image Forensics in particular
  - The methods and methodology are largely shared with Steganalysis
- Is there room for collaboration?
  - Machine Learning
  - Sound methodology