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Real-World Steganography and Steganalysis

Martin Beneš

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Short Bio

Bc., Information Technology
Brno University of Technology

M. Sc., Statistics and Machine Learning
Linköping University

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R&D Internship
Blindspot.ai, Prague

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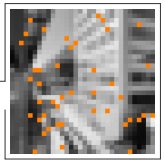
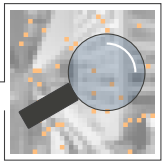
Research and Interests

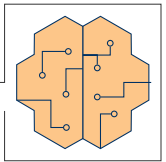
Digital image steganography



Digital image steganalysis



Machine learning

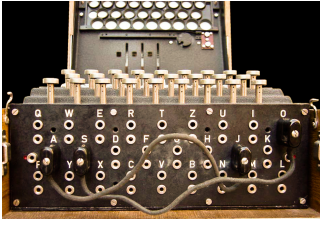


Outline

1. My bio
2. **Establishing steganography**
3. State of “real-world” steganography
4. State of steganography research

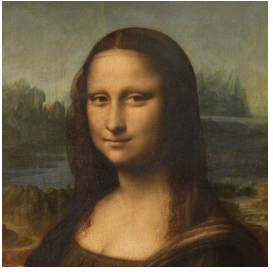
Methods of Secret Communication

Cryptography



conceals the meaning
of the message

Steganography



conceals the existence
of the secret message

Images: Wikimedia.org

Possible Applications for Steganography

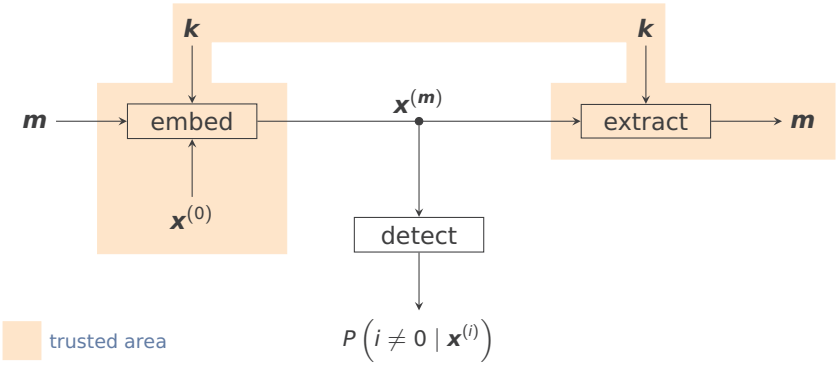
Persecutive communication environments

- Students during test
- Prisoners
- Organized crime
- Malware
- Intelligence agencies
- Corporate espionage
- Dissidents in repressive regimes
- Journalists under censorship
- Communication in conflict zones

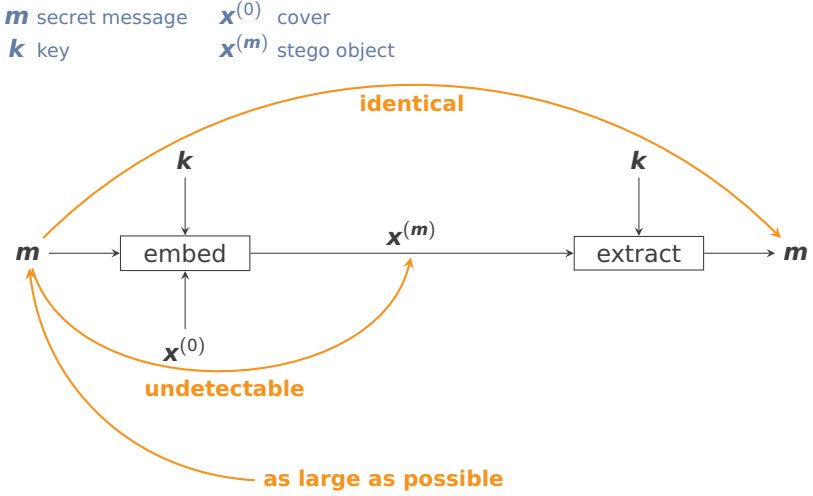
Image: valorreplicas.com (with friendly permission)

Steganographic System

$\boldsymbol{m}$ secret message
$\boldsymbol{k}$ key
$\boldsymbol{x}^{(0)}$ cover
$\boldsymbol{x}^{(\boldsymbol{m})}$ stego object



Steganographic System



How to Embed a Message into a Cover?

File bytes

Directly modify the bytes.

Append after EOF.

File structure

Exploit the format (e.g., “hidden” marker)

Embed into the metadata.

File data

Modify the data itself.

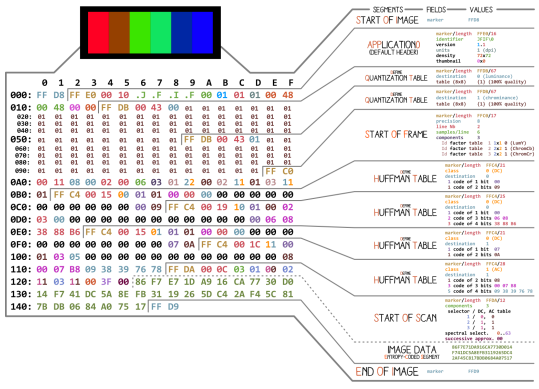
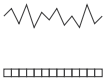


Image: Ange Albertini

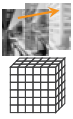
Types of Covers

Audio

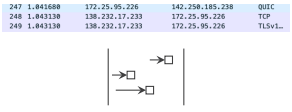


Image

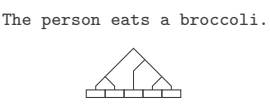
Video



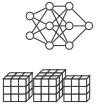
Network traffic



Text



Neural network weights

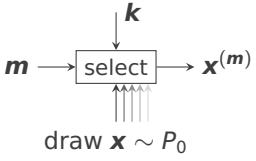


Steganographic channels are typically in the compressed domain.

Approaches to Steganography

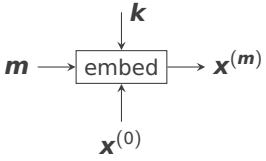
Cover selection

Select the cover that carries the desired message.



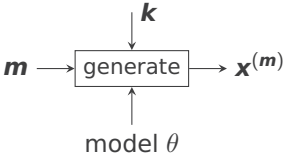
Cover modification

Modify a cover to embed the desired message.



Cover synthesis

Generate a cover that carries the desired message.



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1. My bio
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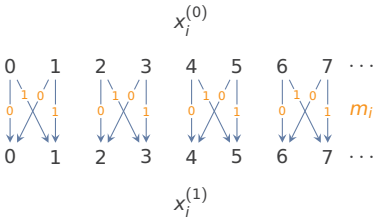
3. **State of “real-world” steganography**
4. State of steganography research

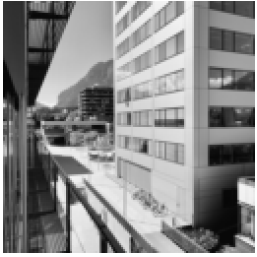
LSB Steganography

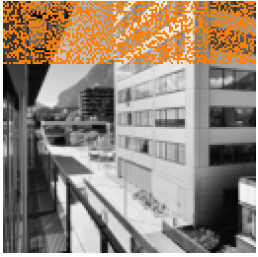
Hide the message ***m*** in the least significant bits (LSBs) of the media data.

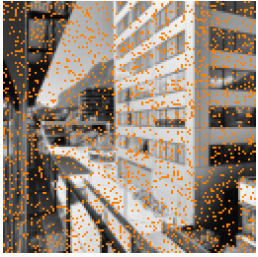
LSB replacement (LSBR)

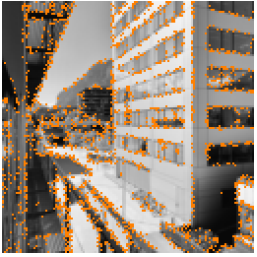


Selection of Embedding Positions

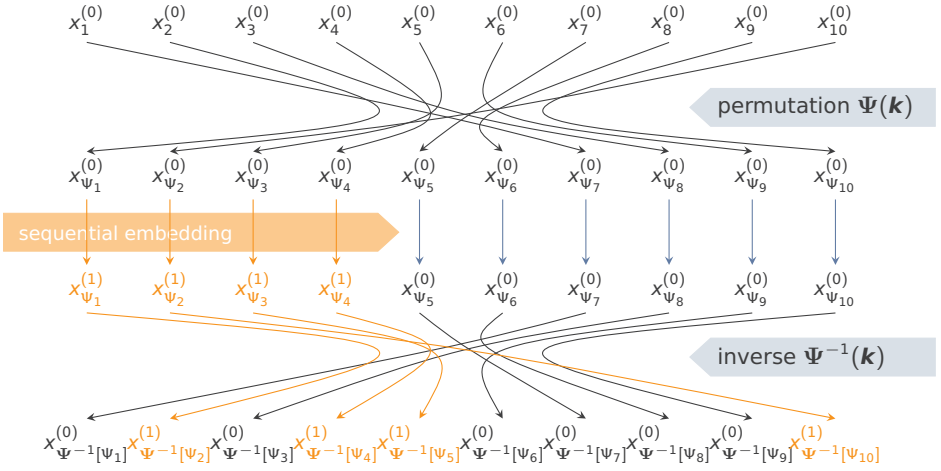

cover


sequential ($p = 0.25$)


spread ($p = 0.25$)


adaptive ($p = 0.25$)

Key-Dependent Permutation



Available Steganographic Tools

Image pixels	steghide	jphide	openstego	...
JPEG coefficients	jsteg	F5	outguess	...
Audio	mp3stego	spectrology	...	

Open-source stego tools

Most public stego tools are decades **old** and use **insecure** steganography.

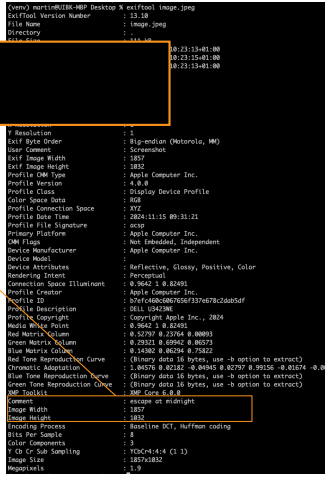
Publishing stego tools is ethically questionable, because it may help criminals.

Andreas Westfeld, Andreas Pfitzmann. Attacks on steganographic systems. Springer IH, 1999.
Graeme Bell, Yeuan-Kuen Lee. A Method for Automatic Identification of Signatures of Steganography Software. IEEE TIFS, 2010.
Daniel Lerch. Stego-collection. https://github.com/daniellerch/stego-collection
Daniel Lerch. Steganography Tools. https://daniellerch.me/stego/intro/tools-en/

Forensic Tools against Naïve Steganography

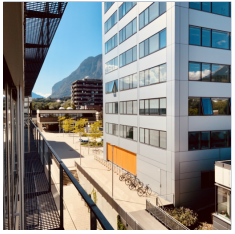
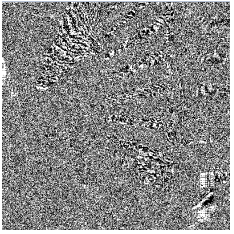
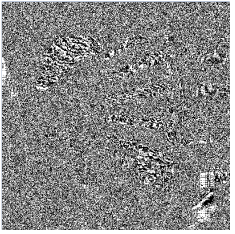
```
Comment                         : escape at midnight
Image Width                     : 1857
Image Height                    : 1032
```

File bytes	hexdump	binwalk	...
File structure	exiftool	strings	...
Data	visual analysis	Aperi'Solve	...



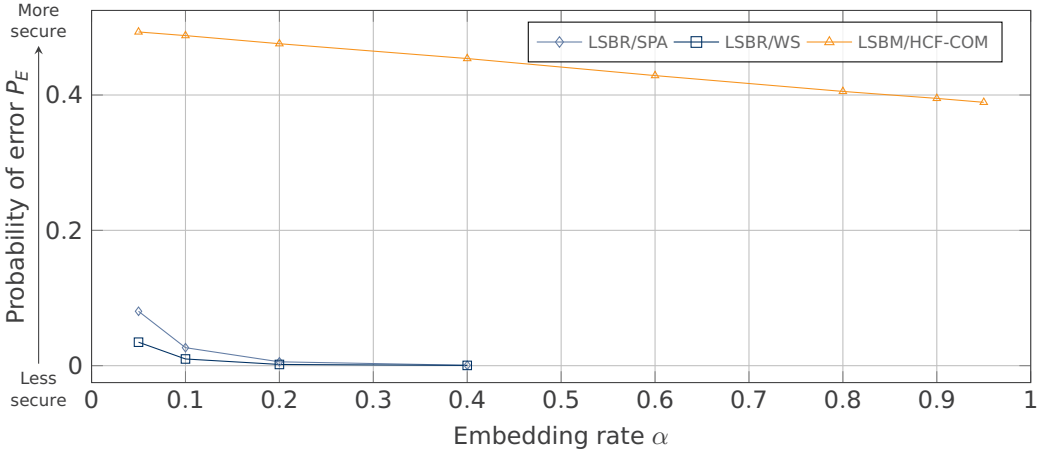
https://www.aperisolve.com/

Visual Analysis

	Cover	Cover LSB	Stego LSB
Natural images			
Computer graphic			

Sequential embedding may be visible in the image LSB plane.

Security of LSB Steganography



10 000 grayscale images from the BOSSBase dataset, size 512^2, LSBR/M without coding ($e = 2$). Training set 50%.

LSB Steganography

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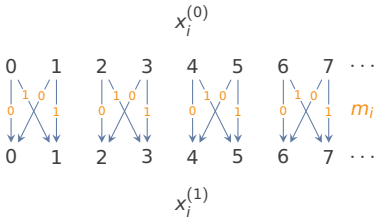
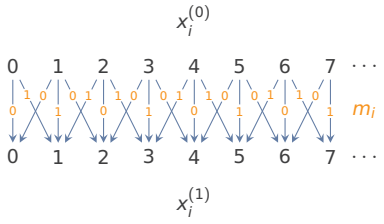
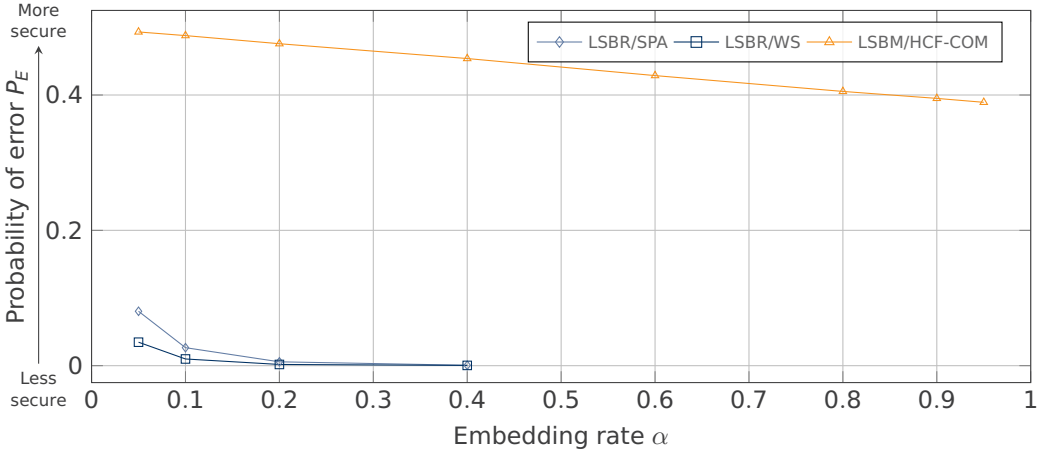
LSB replacement (LSBR)



LSB matching (LSBM)

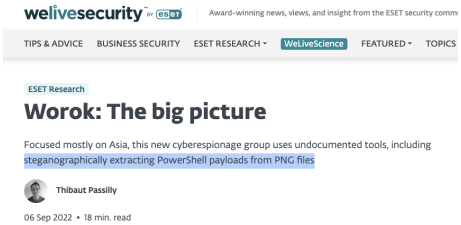


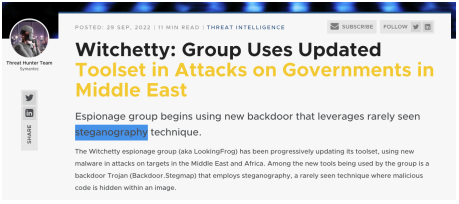
Security of LSB Steganography



10 000 grayscale images from the BOSSBase dataset, size 512^2, LSBR/M without coding ($e = 2$). Training set 50%.

Real World Cases of Steganography





There is little evidence of steganography being used in the digital communication.

(perhaps due to its nature to remain hidden)

https://www.welivesecurity.com/2022/09/06/worok-big-picture/
https://www.security.com/threat-intelligence/witchetty-steganography-espionage
Mukesh Dalal, Mamta Juneja: A survey on information hiding using video steganography. Springer AIR, 2021.

Real World Cases of Steganalysis

Common task during challenges, competitions, and CTFs.

A relevant competence for

- intelligence services and
- law–enforcement agencies.

UNCOVER project (EU Horizon 2020)

V. Leask, R. Cogranne, D. Borghys, H. Bruyninckx. UNCOVER: Development of an efficient steganalysis framework for uncovering hidden data in digital media. ACM ARES, 2022.
https://alaska.utt.fr/
https://www.uncoverproject.eu/

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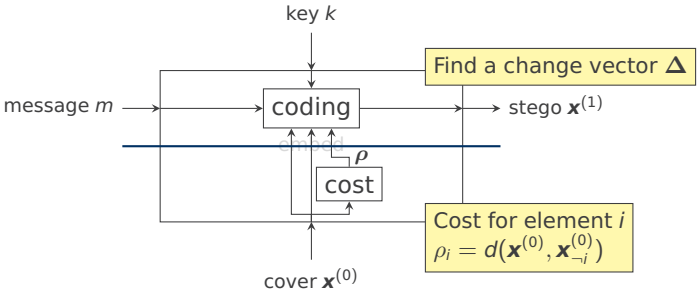
1. My bio
2. Establishing steganography
3. State of “real-world” steganography
4. **State of steganography research**

Paradigms of Modern Steganography

Separation principle

Two step embedding

- cost calculation
- message coding

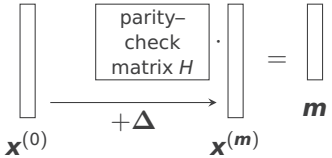


$$\boldsymbol{x}^{(0)}_{\neg i} = \{x^{(0)}_0, \ldots, x^{(0)}_{i-1}, x^{(1)}_i, x^{(0)}_{i+1}, \ldots, x^{(0)}_N\}$$

Steganographic Syndrome Coding

Posed as a contrained optimization problem.

$$\underbrace{\min_{\Delta} \sum_{i=1}^{N} \Delta_i \cdot \rho_i}_{\text{optimization}} \text{, s.t., } \underbrace{H \cdot x^{(m)} = m}_{\text{constraint}}$$



Objectives of coding methods

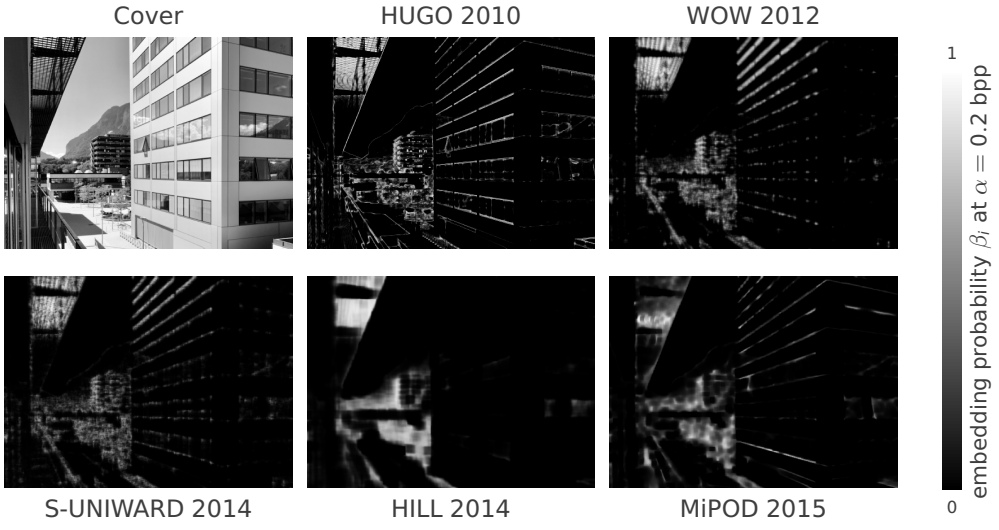
- Reduce # of changes (Hamming codes)
- Avoid saturation (wet paper codes)
- Minimize cost (trellis codes)

Example:

$\boldsymbol{m} = 0\mathbf{1}\ldots$

i	1	2	3	4	$\cdots$
$x_i^{(0)}$	42	26	14	98	$\cdots$
ρ_i	0.05	0.14	0.02	1.10	$\cdots$
			$m_2 = 1$		
Δ_i	1	0	1	0	$\cdots$
$x_i^{(m)}$	43	26	13	98	$\cdots$

Comparison of Cost Functions



Modern Steganalysis

Targeted attacks
= against a stego method

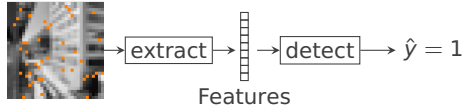
Compatibility attacks
= against a cover

Handcrafted features

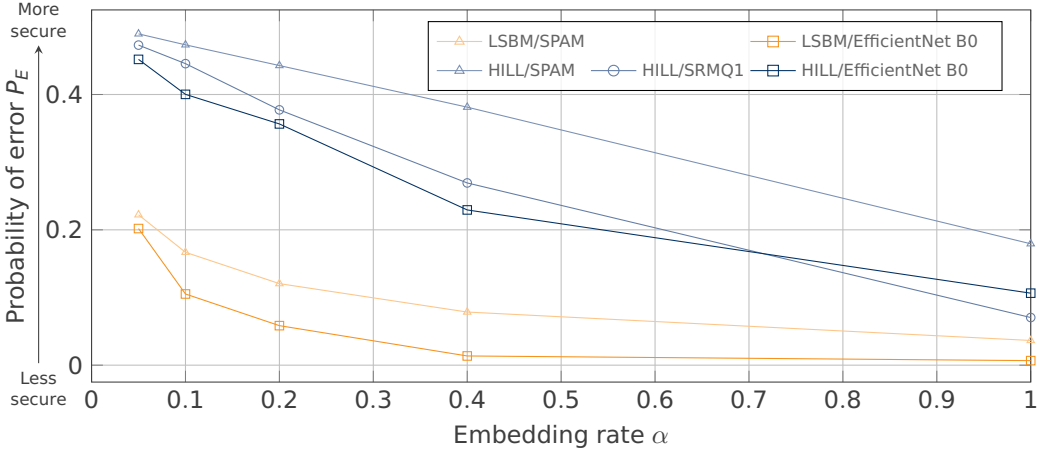
Project the image to a feature space and apply a learning-based detector.

Neural networks

Architectures: *EfficientNet B0*, *SRNet*



Security of Modern Steganography



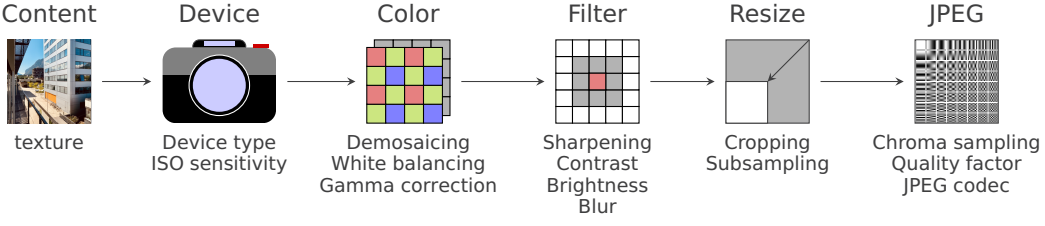
10 000 grayscale images from the BOSSBase dataset, size 512^2, LSBM without coding ($e = 2$), HILL with optimal coding. Training set 50%.

The Source of Covers

Cryptography needs a good random number generator.

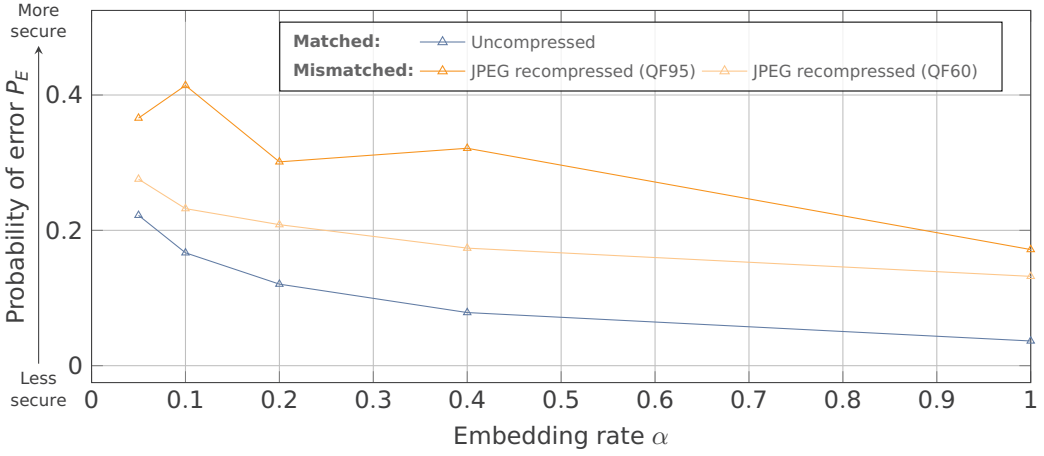
Steganography needs a good source of covers.

Cover source



A. Mallet, M. Beneš, R. Cogranne. Cover-source mismatch in steganalysis: systematic review. EURASIP JIS, 26, 2024.

Cover–Source Mismatch



10 000 grayscale images from the BOSSBase dataset, size 512^2, `libjpeg-turbo`, LSBM. Training set 50%. SPAM+FLD.

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Bedankt!

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martin.benes@uibk.ac.at

Guest Lecture · University of Twente, The Netherlands, 11 March 2025