Minimizing Embedding Impact in Steganography using Trellis-Coded Quantization

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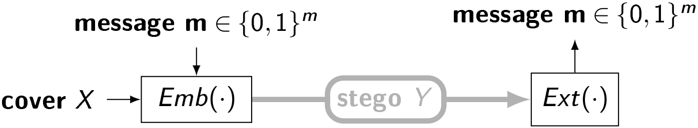
Steganography of Real Digital Media

Cover distribution of real digital media is too complex to be preserved exactly.



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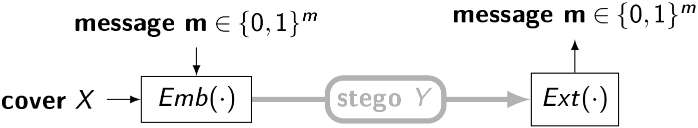

Steganography by cover modification:
Stego object Y is produced by slightly modifying some of the elements (pixels, DCT coefficients, ...) in X.

We assume binary embedding operation.

X, $Y \in \{0,1\}^n$ are obtained via mod 2 of cover elements.

Embedding Impact

Total impact of embedding (distortion metric): $x_i, y_i \in \{0, 1\}$

$$D(\mathbf{x}, \mathbf{y}) = \|\mathbf{x} - \mathbf{y}\|_\rho = \sum_{i=1}^{n} \rho_i |x_i - y_i|,$$

$\rho_i \in [0, \infty)$ is a cost of changing ith cover element.
Wet elements ($\rho_i = \infty$) should not be modified at all.

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Examples of detectability measures:

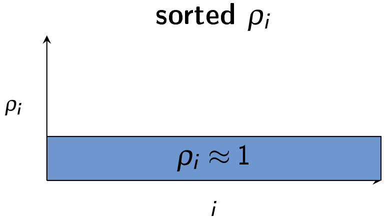
- $\rho_i = 1\ \forall i$ then $D(\mathbf{x},\mathbf{y})$ is total number of emb. changes
- $\rho_i = 1\ i \in Dry$ and $\rho_i = \infty\ i \in Wet \Rightarrow$ Wet Paper Channel
- $\rho_i = Q - 2e_i$ Perturbed Quantization
  Q ... quantization step, $0 \le e_i \le \frac{Q}{2}$ ... quant. error

PROBLEM: create practical algorithm for embedding m bits in n element cover such that $D(\mathbf{x},\mathbf{y})$ is minimal.

Distortion Profiles

Bounded distortion ($\rho_i < \infty$):

- constant profile



Distortion Profiles

Bounded distortion ($\rho_i < \infty$):

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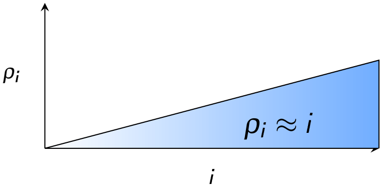
- linear profile

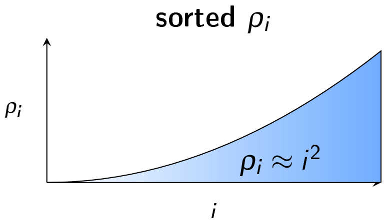
sorted ρ_i



Distortion Profiles

Bounded distortion ($\rho_i < \infty$):

- constant profile
- linear profile
- square profile



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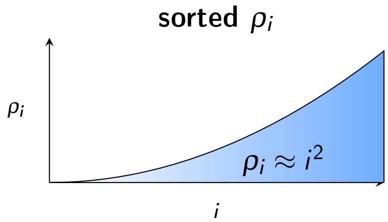
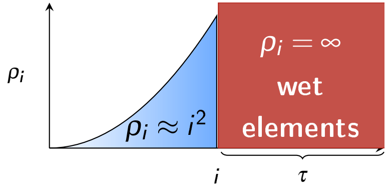


Wet Paper Channel (ρ_i may be ∞):

Wet Paper Channel
with square profile
relative wetnes $\tau = 0.5$



Relative Payload & Embedding Efficiency

m ... # of msg bits, k ... # of semi-dry elements ($\rho_i < \infty$)

Relative payload: $\alpha = m/k$

- required to be small to stay undetectable ($\alpha \approx 1/10$)
- has to decrease with increasing cover size **(Square Root Law)**

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Embedding efficiency: $e = m/D(\mathbf{x}, \mathbf{y})$

Number of bits embedded per unit distortion.

Upper bound:

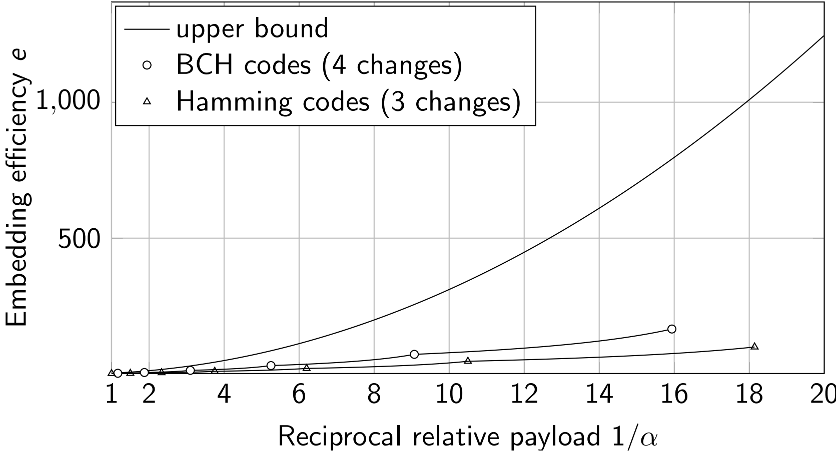
Constant profile ($\rho_i = 1$):

$$e \leq \frac{\alpha}{H^{-1}(\alpha)}$$

Other profiles:

See paper.

State of the Art - Square Profile



Goal: design new algorithms being able to handle arbitrary profile very close to the bound.

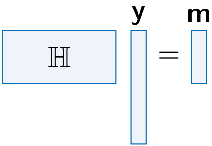
Syndrome Coding Approach

Common tool for constructing steganographic schemes.

$\mathbb{H} \in \{0,1\}^{m \times n}$ ... **shared parity-check matrix**

Extraction function:

$$\mathbf{m} = Ext(\mathbf{y}) = \mathbb{H}\mathbf{y}$$



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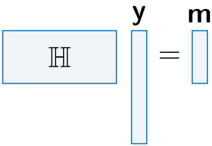


$$\mathbf{m} = Ext(\mathbf{y}) = \mathbb{H}\mathbf{y}$$

Embedding function:

$$\mathbf{y} = Emb(\mathbf{x}, \mathbf{m}) = \arg \min_{\mathbb{H}\mathbf{y}=\mathbf{m}} D(\mathbf{x}, \mathbf{y})$$

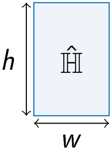
Replace x with y, such that $D(\mathrm{x}, \mathrm{y})$ is minimal and $\mathbb{H}\mathrm{y} = \mathrm{m}$.

Embedding is NP hard problem for general parity-check matrix $\Rightarrow$ we need some structure in $\mathbb{H}$.

Syndrome Trellis Codes (1/3)

Parameters: $h \in \{1, \ldots, 15\}$ **... constraint height,** $w = 1/\alpha$

Parity-check matrix $\mathbb{H} \in \{0,1\}^{m \times n}$**:**



generate $\hat{\mathbb{H}} \in \{0,1\}^{h \times w}$ **pseudo-randomly**

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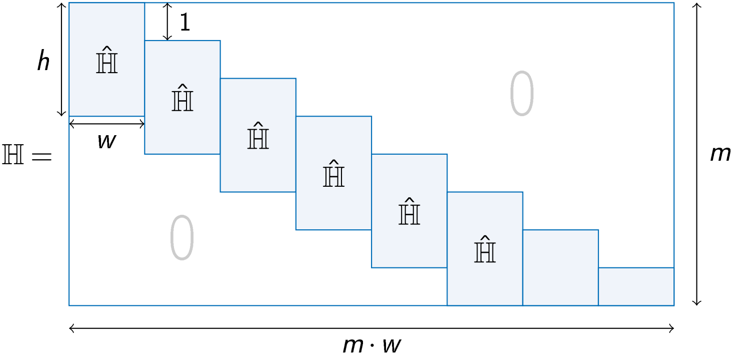

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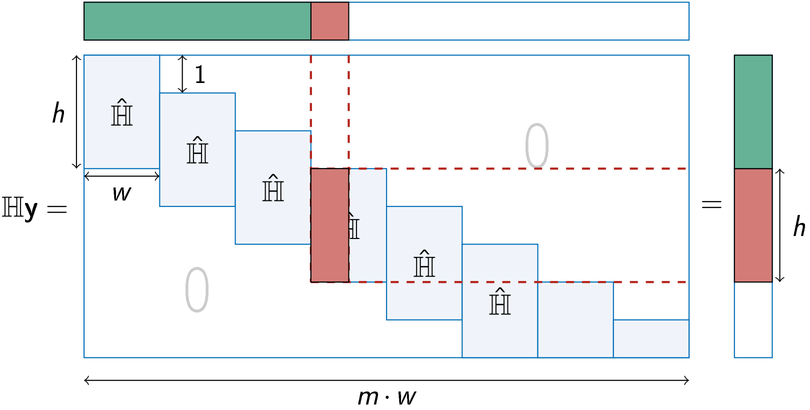


Syndrome Trellis Codes (2/3)

Syndrome trellis ($h = 2$): $\mathbf{x} = (0, \ldots, 0)$, $\mathbf{m} = (0, 1, \ldots)$

candidates for stego

$\mathbf{y} = (0, 0, ?, \ldots, ?)$

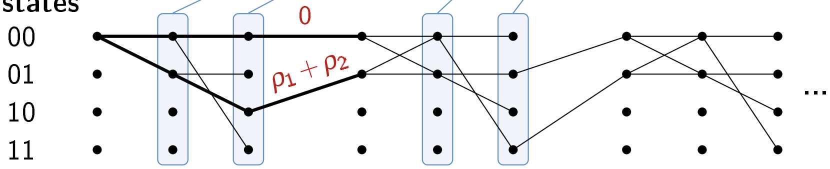
$\mathbf{y} = (\underbrace{1, 1}, ?, \ldots, ?)$

2 elements changed

$\Rightarrow$ **cost** $= \rho_1 + \rho_2$

$$\mathbb{H} = \begin{pmatrix} 1 & 1 & & & & & & \\ 0 & 1 & 1 & 1 & & & & \\ & & 0 & 1 & 1 & 1 & & \\ & & & & 0 & 1 & 1 & 1 \end{pmatrix}$$

2^h states



$\mathbf{m}_1 = 0$ $\mathbf{m}_2 = 1$

Syndrome Trellis Codes (3/3)

Viterbi algorithm (optimal quantizer):

Finds the shortest path (closest stego object)

in the syndrome trellis.

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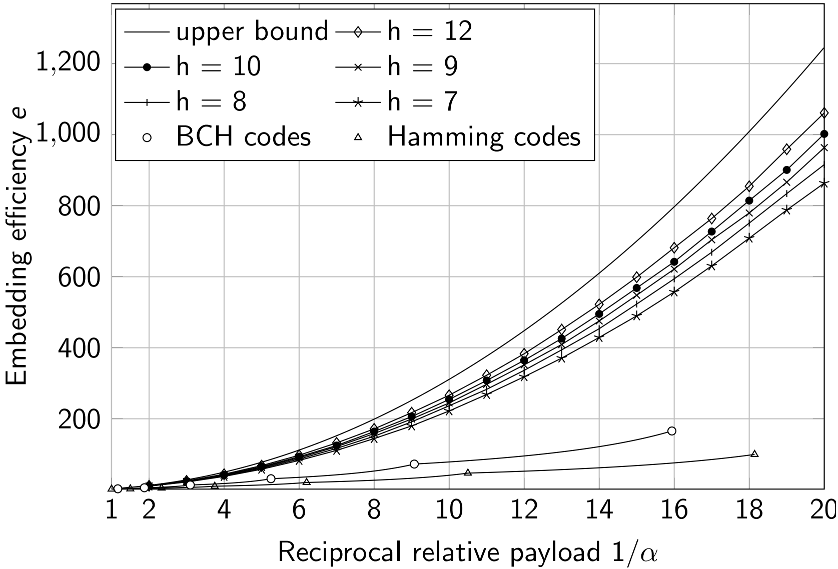
Complexity:

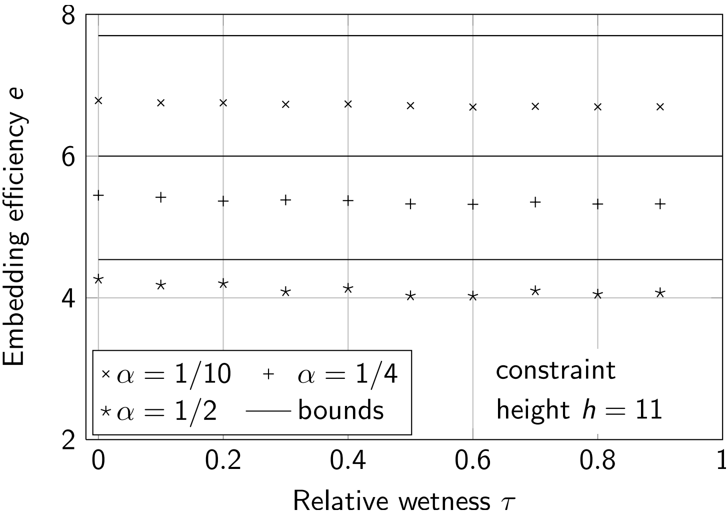
Time and space $\mathcal{O}(2^h n)$.

Whole cover object can be used for embedding.

Results - Square Profile

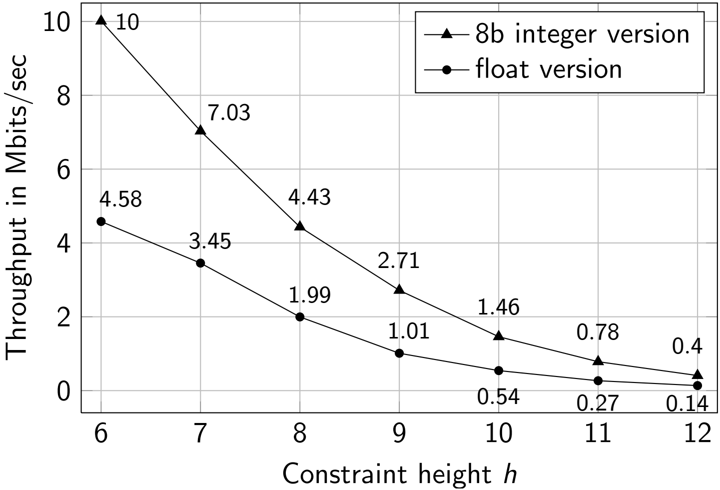


Wet Paper Channel with Constant Profile



No performance drop with wet elements, profile independent!

Results - Speed (independent of α)



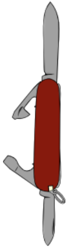
1MPix image embedded in less than 2 seconds!

Conclusion

Principle of minimal embedding impact
is an important design rule for steganography.

Syndrome Trellis Codes
allows to minimize the embedding impact

- for arbitrary profile (even with wet elements)
- for arbitrary rational relative payload $\alpha \leq 1/2$
- with near-optimal embedding efficiency
- where speed can be traded for performance.



Optimized C++ and Matlab code available.

http://dde.binghamton.edu/download

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Do you want to join the game?

BOSS

Break Our Steganographic System

Steganalytic chalange is coming up in 2010!
1000 images, 500 with a hidden message
Guess which ones!

`http://boss.gipsa-lab.grenoble-inp.fr`