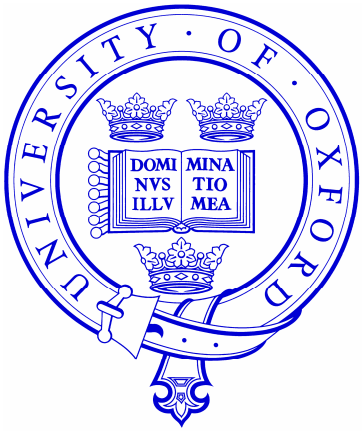
A Weighted Stego Image Detector for Sequential LSB Replacement



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Outline

- Spread and sequential LSB replacement
- The Weighted Stego Image (WS) method
- WS for sequential embedding
- Performance

LSB Replacement

- The **cover** is a stream of N words (e.g. pixel values in image, audio samples).
- The **payload** is arranged as stream of M bits.
- The cover object's least significant bits are overwritten by the payload to form the **stego object**.

1. **Spread embedding: overwrite a pseudorandom sequence of M LSBs.**

Each cover word has LSB flipped, independently, with probability $M/2N$.

2. **Sequential embedding: overwrite the first M LSBs.**

First M cover words have LSB flipped, independently, with probability $1/2$.

In either case,

- the same number of LSBs are flipped by the embedding process,
- modifications are invisible to the eye,

but sequential embedding "ought to be" easier to detect statistically.

Steganalysis of LSB Replacement

There are many detectors* of LSB replacement:

- "RS" Fridrich, Goljan, & Du, 2001
- "Sample Pairs" Dumitrescu, Xu, & Wang, 2002
- "Pairs" Fridrich, Goljan, & Soukal, 2003
- "Least-Squares" Lu, Luo, Tang & Shen, 2004
- "Triples" Ker, 2005
- "ML Structure" Ker, 2007

- "Chi-Square" Westfeld & Pfitzman, 1999
- "Max. Likelihood" Dabeer et al, 2004
- "Empirical PMF" Draper et al, 2005

- "Weighted Stego" Fridrich & Goljan, 2004

*payload size estimators

Steganalysis of LSB Replacement

- "RS"
- "Sample Pairs"
- "Pairs"
- "Least-Squares"
- "Triples"
- "ML Structure"

Use "structural" analysis of LSB flipping.

- *Highly sensitive to spread LSB replacement.*
- *Ineffective against sequential LSB replacement.*
- *Cannot be adapted to work in the sequential case.*

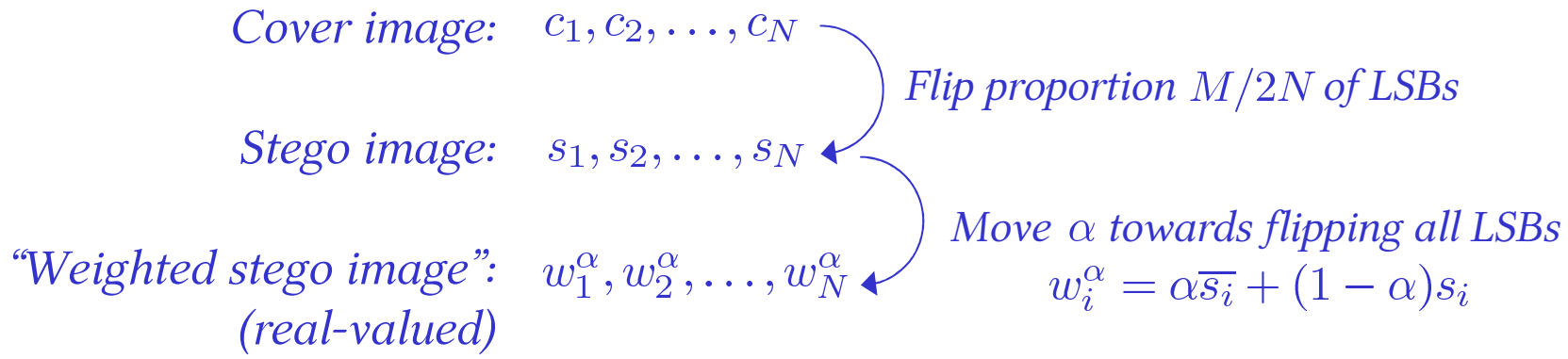
- "Chi-Square"
- "Max. Likelihood"
- "Empirical PMF"

Based on signal-processing techniques.

- *Poor sensitivity for sequential or spread embedding.*
- *Can sometimes be specialised to the sequential case, but remain weak.*

- "Weighted Stego" — The subject of this talk.
  - *Quite good sensitivity for spread LSB payload.*
  - *About equally good against sequential LSB payload.*

The WS Method



Theorem [Fridrich & Goljan, 2004]

The function $E(\alpha) = \sum_{i=1}^{N} \left(w_i^\alpha - c_i\right)^2$ is minimized at $\alpha = M/2N$.

WS Steganalysis

1. Estimate cover by filtering stego image: $\hat{c}_i$ = average of surrounding four s_i.
2. Estimate size of payload

$$\hat{M} = 2N \operatorname*{argmin}_{\alpha} \sum_{i=1}^{N} \left(w_i^\alpha - \hat{c}_i\right)^2 = 2\sum_{i=1}^{N} (s_i - \hat{c}_i)(s_i - \overline{s_i}).$$

Sequential WS

Cover image: $c_1, c_2, \ldots, c_N$

Flip first M LSBs with probability $1/2$

Stego image: $s_1, s_2, \ldots, s_N$

Go halfway to flipping first j LSBs

Weighted stego image: $w_1^j, w_2^j, \ldots, w_N^j$

$$w_i^j = \begin{cases} \frac{1}{2}\overline{s_i} + \frac{1}{2}s_i, & i \le j \\ s_i, & i > j \end{cases}$$

Theorem

The function $F(j) = \sum_{i=1}^{N} \left(w_i^j - c_i\right)^2$ is minimized at $j = M$.

Sequential WS Steganalysis

1. Estimate cover by filtering stego image: $\hat{c}_i$ = average of surrounding four s_i.
2. Estimate size of payload

$$\hat{M} = \underset{j}{\operatorname{argmin}} \left(\sum_{i=1}^{j} \left(\left(\tfrac{1}{2}s_i + \tfrac{1}{2}\,\overline{s_i}\right) - \hat{c}_i \right)^2 + \sum_{i=j+1}^{N} \left(s_i - \hat{c}_i\right)^2 \right).$$

Efficient Implementation

We need to determine

$$\hat{M} = \operatorname*{argmin}_j \underbrace{\left(\sum_{i=1}^{j} \left(\left(\tfrac{1}{2} s_i + \tfrac{1}{2}\,\overline{s_i}\right) - \hat{c}_i \right)^2 \; + \sum_{i=j+1}^{N} \left(s_i - \hat{c}_i\right)^2 \right)}_{F(j)} \qquad (*)$$

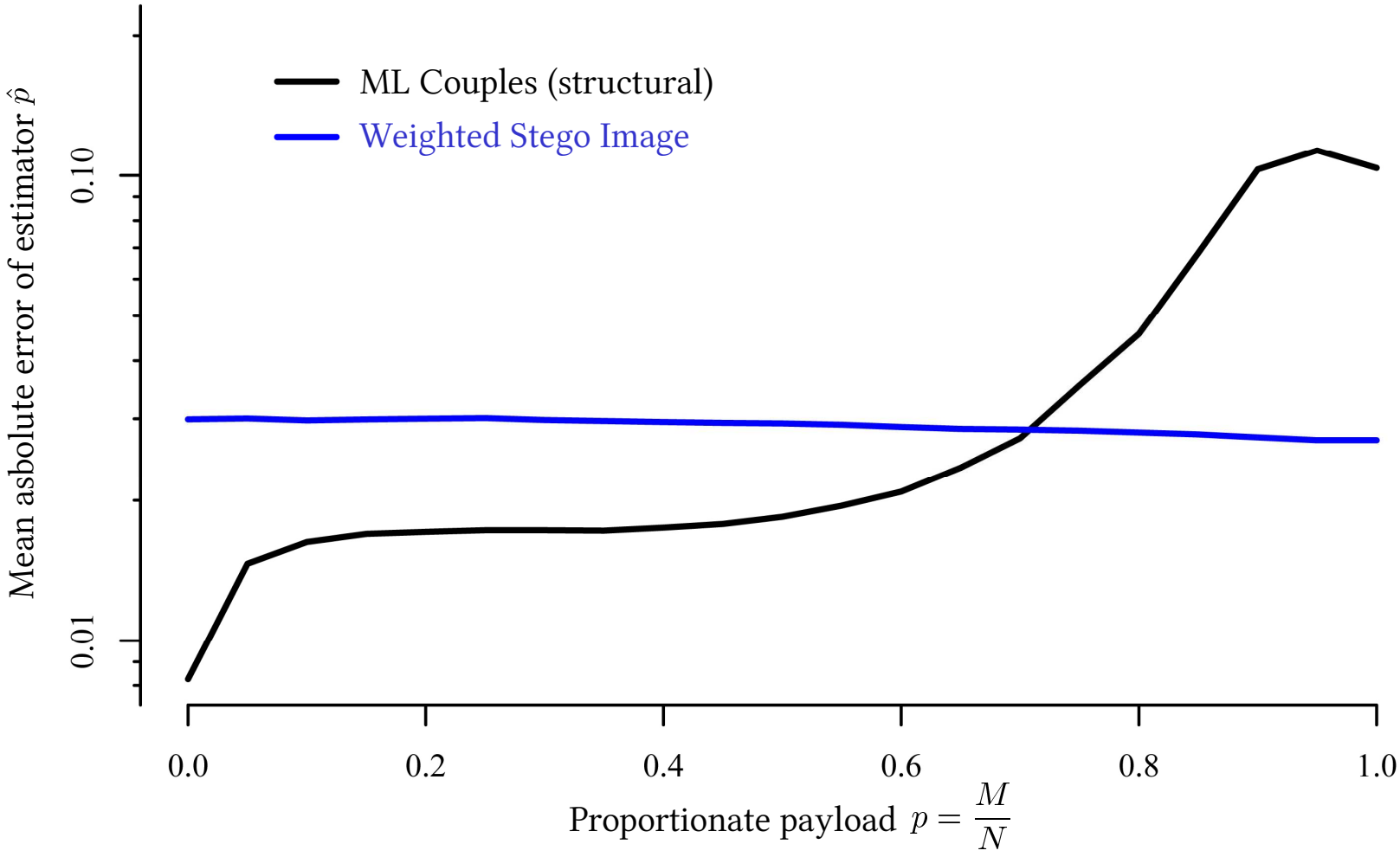
The naïve implementation is $O(N^2)$ ...

... but the recurrence

$$g_0 = 0$$
$$g_j = g_{j-1} + \left(\tfrac{1}{2}(s_j + \overline{s}_j) - \hat{c}_j\right)^2 - \left(s_j - \hat{c}_j\right)^2$$

satisfies $F(j) = g_j + \text{constant}$ *thus* $(*)$ *can be found in linear time.*

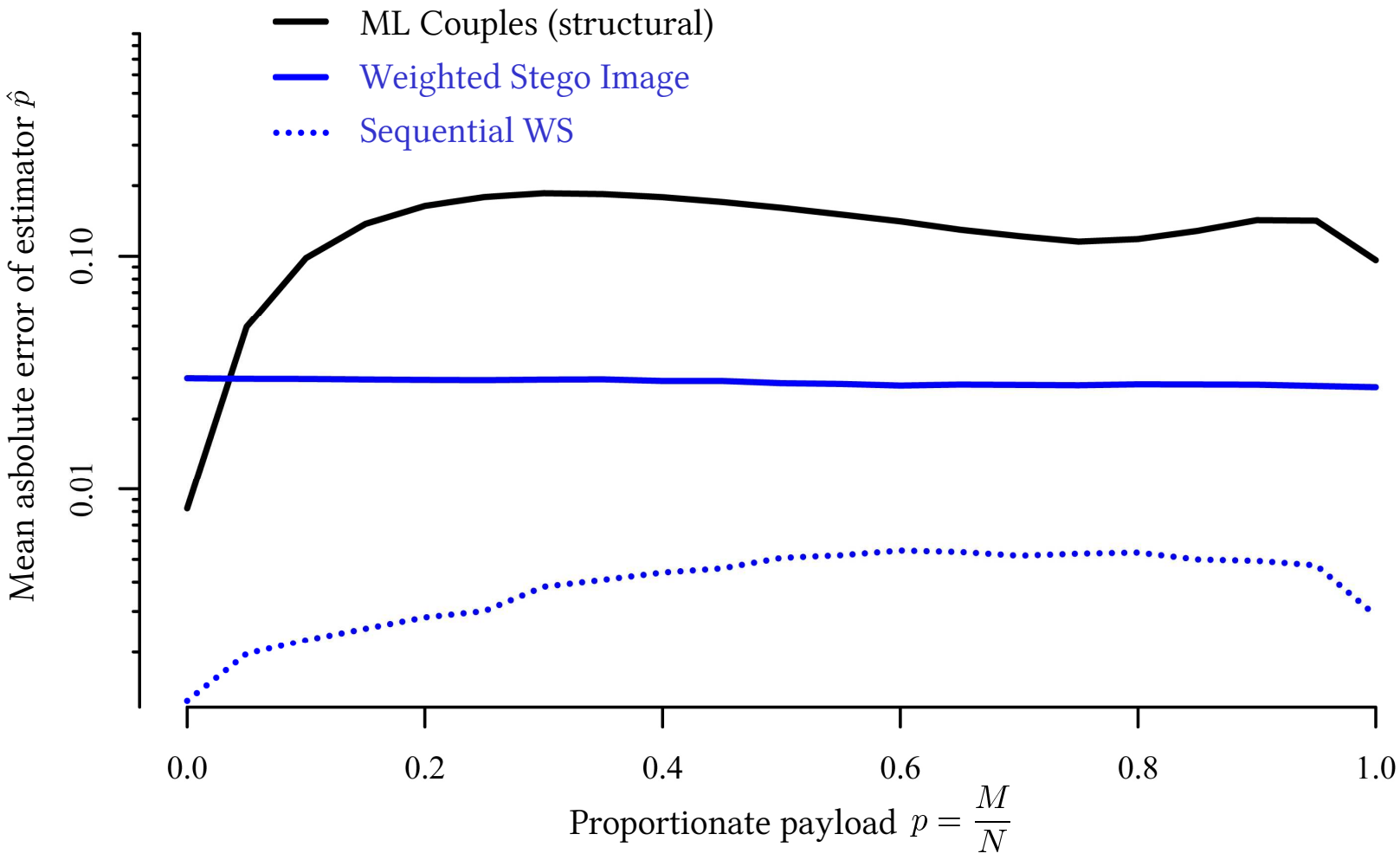
Performance: Spread Embedding



Experimental data from:

- 3000 grayscale bitmap cover images 0.3Mpixels,
- 20 different-sized payloads in each, creating 60000 stego images.

Performance: Sequential Embedding



Experimental data from:

- 3000 grayscale bitmap cover images 0.3Mpixels,
- 20 different-sized payloads in each, creating 60000 stego images.

Conclusions

- Sequential LSB replacement is one of the worst possible choices to embed data secretly.

  The embedding procedure has structure, and the payload is located predictably.

- There was no previous sensitive detector for it.

  The most sensitive ("structural") detectors for spread LSB replacement do not adapt to sequential embedding.

- The WS detector can be adapted, and the new detector's performance is superior.
  - *1000 1.5Mpixel grayscale RAW images from digital cameras;*
  - *Payloads of 500000 bits embedded sequentially;*
  - *Sequential WS payload estimates: over **90%** were within **120** of 500000.*

End

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