NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

SPMS23019 – Incorporating Gale-Berlekamp Switch Game in Image Steganography

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Introduction

Image Steganography

- The process of hiding information (usually a string) within images.
- The least significant bit (LSB) in each pixel value is altered such that it matches the parity of bits in the string.
  - LSB Replacement: Replace LSB with corresponding parity of the string.
  - LSB Matching: Randomly add or subtract 1 from pixel value if parity does not match.

Example: Embed bit value 1 into pixel (0x94)

1	0	0	1	0	1	0	0

LSB Replacement

1	0	0	1	0	1	0	1

LSB Matching

Case add 1:

1	0	0	1	0	1	0	1

Case subtract 1:

1	0	0	1	0	0	1	1

Gale-Berlekamp Switch Game

- Given a matrix of ‘0’s and ‘1’s, each row and column are controlled by a switch.
- Turning on the switch (‘0’ → ‘1’) toggles the parity of the bits across the corresponding row or column.
- Goal is to fine the combination of toggled switches that minimize the number of ‘1’s within the matrix (excluding switches).

Before:

	0	0	0
0	1	0	0
0	0	1	1
0	1	1	0

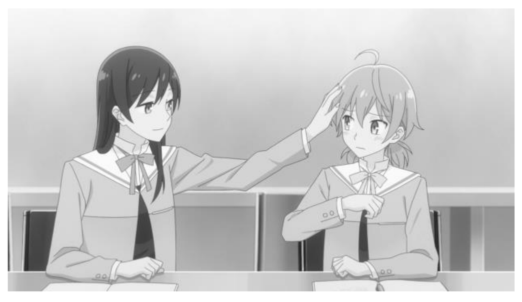
Optimization →

	1	0	0
0	0	0	0
1	0	0	0
0	0	1	0

Number of ‘1’s reduced from 5 to 1

Methodology

Cover Image



LSB Matrix (partial)

1	0	0	1
1	1	0	0
1	1	1	1
0	1	1	0

Information to be embedded
‘Y’ – ASCII 0101 1001

0	1	0
1	1	0
0	1	

With Optimization

1. Matrix containing information to be embedded is XORed with LSB Matrix to identify mismatch in the form of ‘1’.
2. Gale-Berlekamp Swich Game is applied to minimize:
   - number of ‘1’s within the matrix bordered in red, and
   - number of changes to parity of switches.
3. The remaining ‘1’s within the matrix bordered in red as well as changes to the parity of the switches are the bit changes to the cover image.
4. Information can be extracted from the resulting images by turning off all the switches (‘1’ → ‘0’).

1	0	0	1
1	1	0	0
1	1	1	1
0	1	1	0

Treated as column switches

Treated as row switches

All switches are initially turned off, regardless of whether its initial value is ‘0’ or ‘1’

(1) XOR →

1	0	0	1
1	1	1	0
1	0	0	1
0	1	0	0

(2) Optimization →

1	0	0	1
1	0	0	0
0	0	0	0
0	1	0	1

‘1’ signifies mismatch in parity of bit between cover image and information

(3) Embedding →

1	0	0	1
1	1	0	0
0	1	1	1
0	0	1	1

Number of bit changes = 3

Final state of switch is independent of its initial value
- ‘0’ – turned off
- ‘1’ – turned on

Without Optimization

1	0	0	1
1	0	1	0
1	1	1	0
0	0	1	0

Number of bit changes = 4

Findings

- Random bit sequences of various length are generated and tested on greyscale images.
- On average, optimization reduces the number of bit changes by 26%.
- However, as length increases, time taken to solve the linear optimization problem increased exponentially.

Length of information (bits)	Without Optimization	With Optimization	Time Taken (s)
81 (9 × 9 matrix)	39	27	0.313
409 (≈ 20 × 20 matrix)	206	153	57.5
819 (≈ 28 × 28 matrix)	404	308	5292

Conclusion

- Incorporating Gale-Berlekamp Switch Game leads to lesser bit changes to images during Image Steganography.
- Resulting images are less detectable by steganalysis tools and thus more secure.
- However, the high time complexity of solving linear optimization problems suggest that this methodology may not be well-suited for very large data sets.