# 資訊隱藏技術與其應用
# Data Hiding Technique and Its Application


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# Introduction

- ✓ 小明暗戀隔壁班的女同學阿花，一天小明終於鼓起勇氣寫信給阿花
- ✓ 請選擇以下其中一樣在其中打勾：

  □愛情； □友情
- ✓ 阿花回送給他一首詩：

  願君多諒知識淺，選題未答繳白卷

  愛莫能助實有愧，情願送詩供君覽

# Introduction (Cont.)

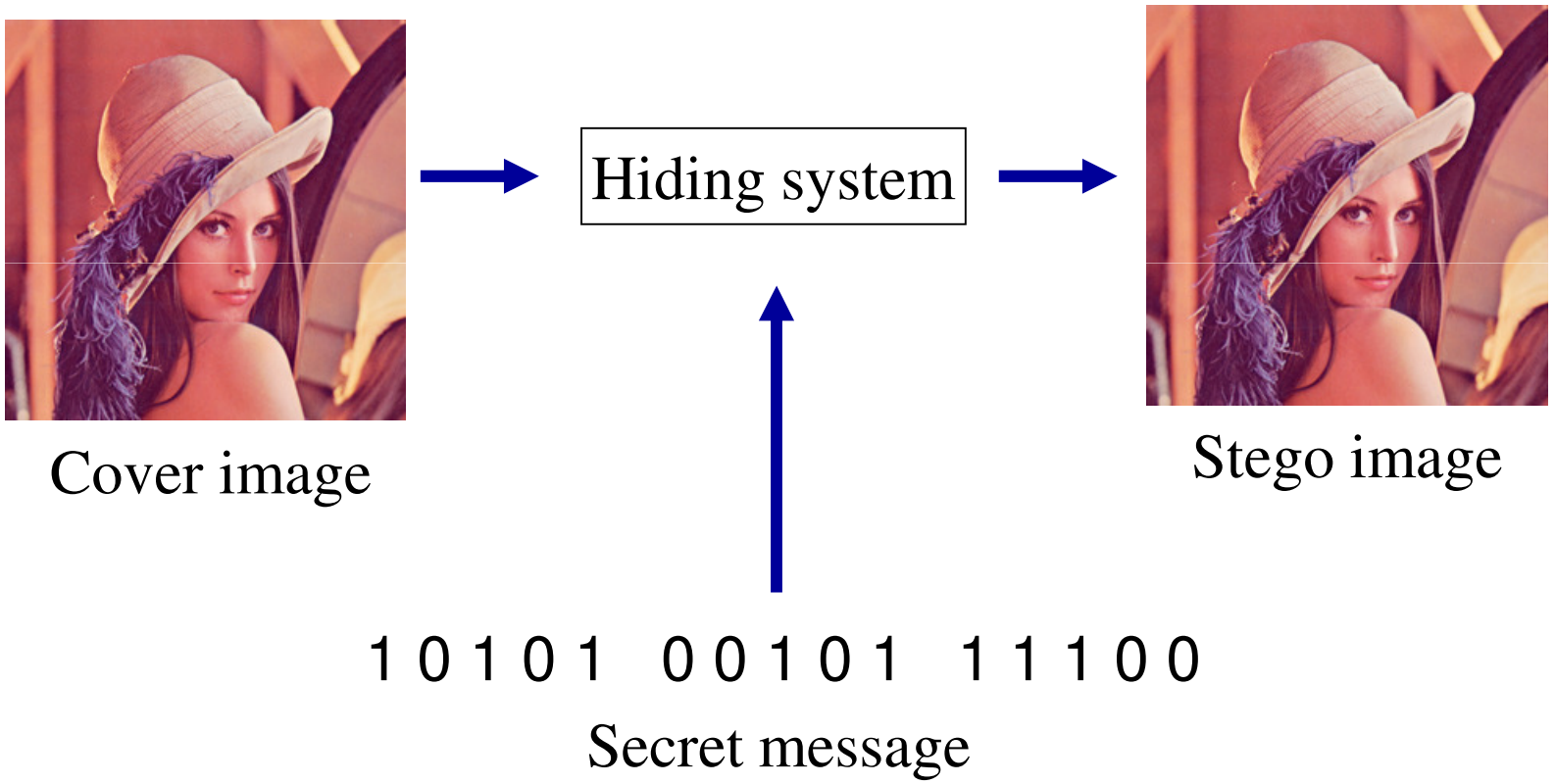
| | |
|---|---|
| 345 | 相思苦 |
| 1573 | 一往情深 |
| 5646 | 無聊死了 |
| 53406 | 我想死你了 |
| 53770 | 我想親親你 |
| 075、9125、184 | 你親我就要愛我一輩子 |
| 0800-956-956 | 恁別贏贏-救摸聊-救摸聊 |

# Introduction (Cont.)

- Crytography
  - RSA (Ron **R**ivest, Adi **S**hamir, and Leonard **A**dleman, 1977)
  - DES (**D**ata **E**ncryption **S**tandard, 1976)
  - AES (**A**dvance **E**ncryption **S**tandard, 2001/11/26)
- Steganography
  - Secret data delivery
  - Visual quality vs. embedding capacity
  - Categories:
    - Compression domain
    - Spatial domain
    - Frequency domain
  - Grayscale image/color image
- Digital Watermarking

# Introduction (Cont.)

- Information hiding (Data hiding)

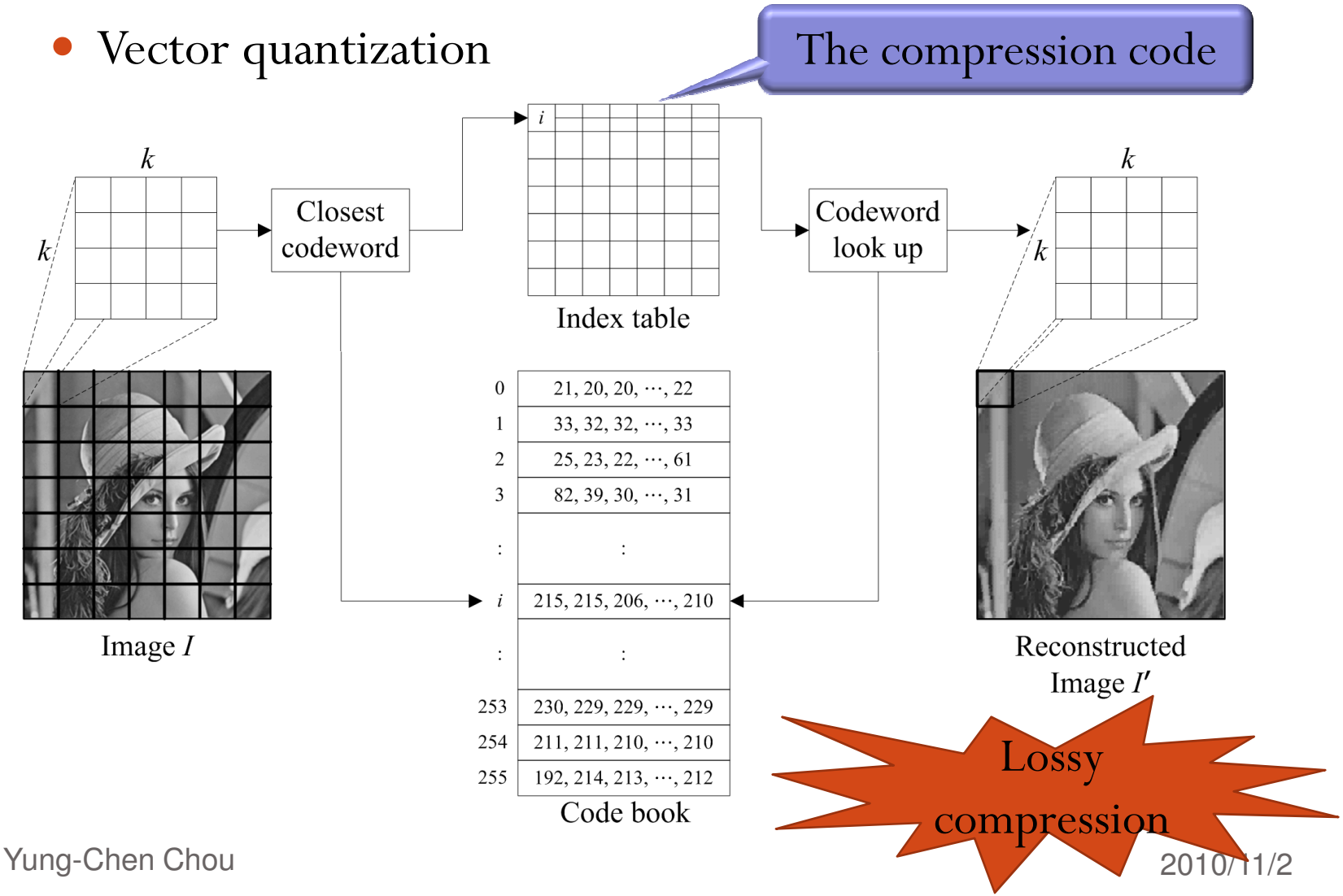


# VQ domain data hiding

資料來源： http://www.peopo.org/kcl137/post/27265

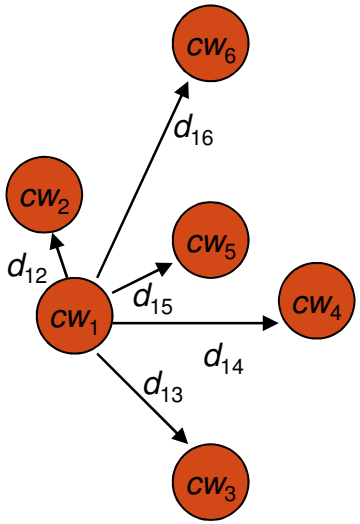
# VQ domain data hiding (Cont.)

- Vector quantization

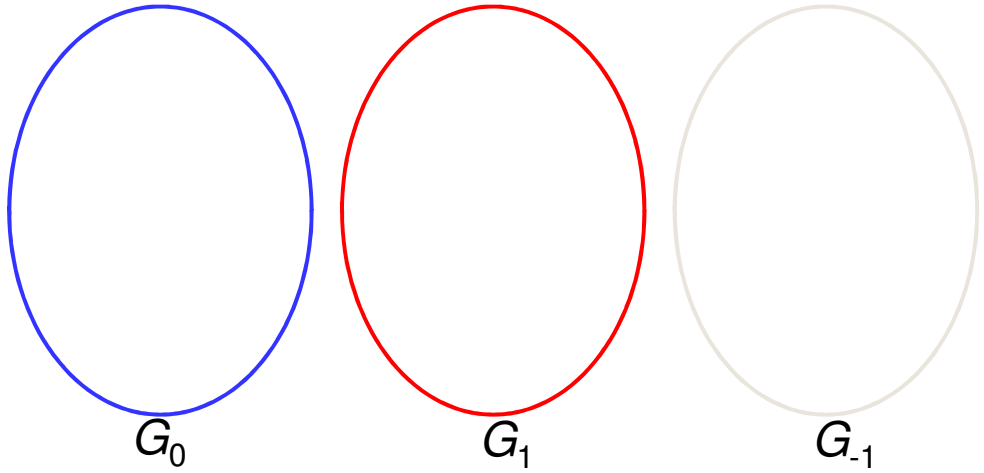


# VQ domain data hiding (Cont.)

- Codeword pairing




$\{d_{12}, d_{13}, d_{14}, d_{15}, d_{16}, d_{23}, d_{24}, d_{25}, d_{26}$
$d_{34}, d_{35}, d_{36}, d_{45}, d_{46}, d_{56}\}$



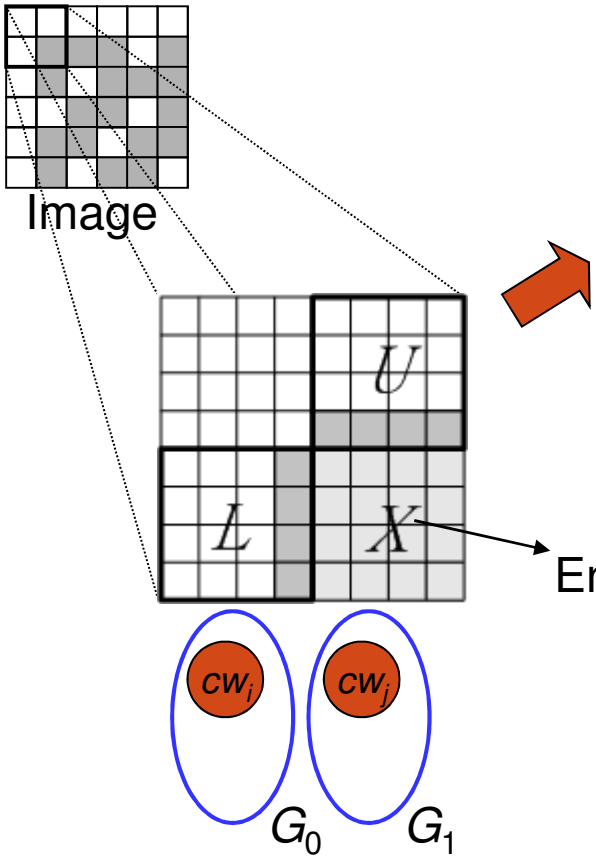

$d_{36} > TH$

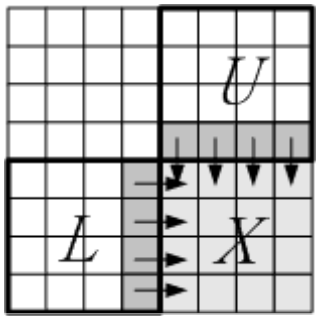
# VQ domain data hiding (Cont.)

- Data hiding

$$SMD(cw_x, NBV_{B_i}) = \sqrt{\sum_{j=0,1,2,3,4,8,12} (cw_x(j) - NBV_{B_i}(j))^2}$$

$NBV_X = \{x_0, x_1, x_3, x_4, X, X, X, x_8, X, X, X, x_{12}, X, X, X\}$




Indicator = '0'

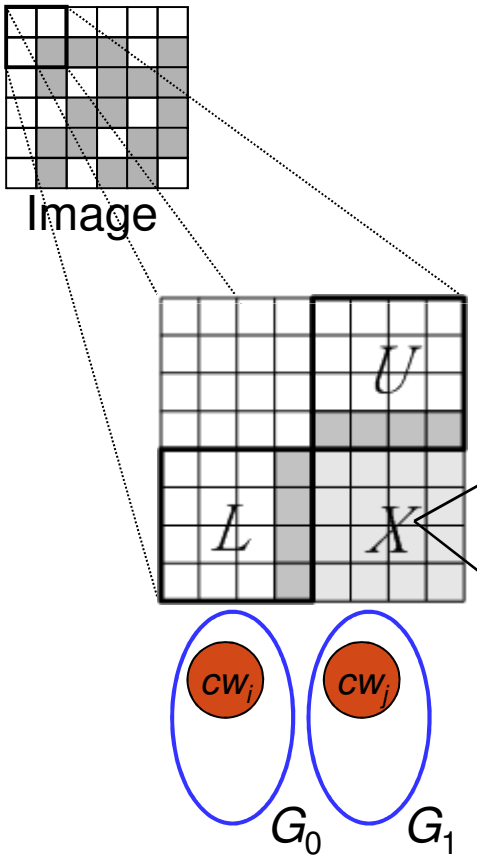
If $SMD(cw_i, NBV_X) < SMD(cw_j, NBV_X)$ then $X$ is replaceable
Else $X$ is non-replaceable

Indicator = '1'

If secret bit = '0' then encode $X$ by $cw_i$
else encode $X$ by $cw_j$

# VQ domain data hiding (Cont.)

- Data extracting and restoring




If SMD($cw_i$) < SMD($cw_j$) and indicator = '0' ➔ restore $X$ by $cw_i$
If SMD($cw_i$) < SMD($cw_j$) and indicator = '1' ➔ restore $X$ by $cw_j$
If SMD($cw_i$) ≥ SMD($cw_j$) and indicator = '0' ➔ restore $X$ by $cw_j$
If SMD($cw_i$) ≥ SMD($cw_j$) and indicator = '1' ➔ restore $X$ by $cw_i$

If $X$ encoded by $cw_i$ then secret bit = '0'

If X encoded by $cw_j$ then secret bit = '1'

# VQ domain data hiding (Cont.)

- Experimental results

| Images | Size of Codebook | Stego image quality (PSNR) | Payload (bits) | Restoration information (bits) | Available embedding capacity (bits) |
|---|---|---|---|---|---|
| Baboon | 256 | 24.16 | 8512 | 1562 | 6950 |
| | 512 | 24.43 | 9824 | 1766 | 8058 |
| | 1024 | 24.80 | 9782 | 1740 | 8042 |
| Jet(F16) | 256 | 30.12 | 11154 | 1786 | 9368 |
| | 512 | 30.98 | 13665 | 2228 | 11437 |
| | 1024 | 31.62 | 13702 | 2308 | 11394 |
| Lena | 256 | 30.54 | 12947 | 2174 | 10773 |
| | 512 | 31.31 | 13922 | 2310 | 11612 |
| | 1024 | 32.32 | 14014 | 2343 | 11671 |
| Pepper | 256 | 30.00 | 12285 | 2023 | 10262 |
| | 512 | 30.65 | 13507 | 2236 | 11271 |
| | 1024 | 31.22 | 14504 | 2403 | 12101 |
| Sailboat | 256 | 26.47 | 10773 | 1789 | 8984 |
| | 512 | 26.95 | 12323 | 2080 | 10243 |
| | 1024 | 27.58 | 11314 | 1955 | 9359 |
| Toys | 256 | 29.28 | 8115 | 1292 | 6823 |
| | 512 | 30.41 | 8795 | 1412 | 7383 |
| | 1024 | 31.66 | 13546 | 2099 | 11447 |

# VQ domain data hiding (Cont.)

- Experimental results

The comparison using Lena as the cover image

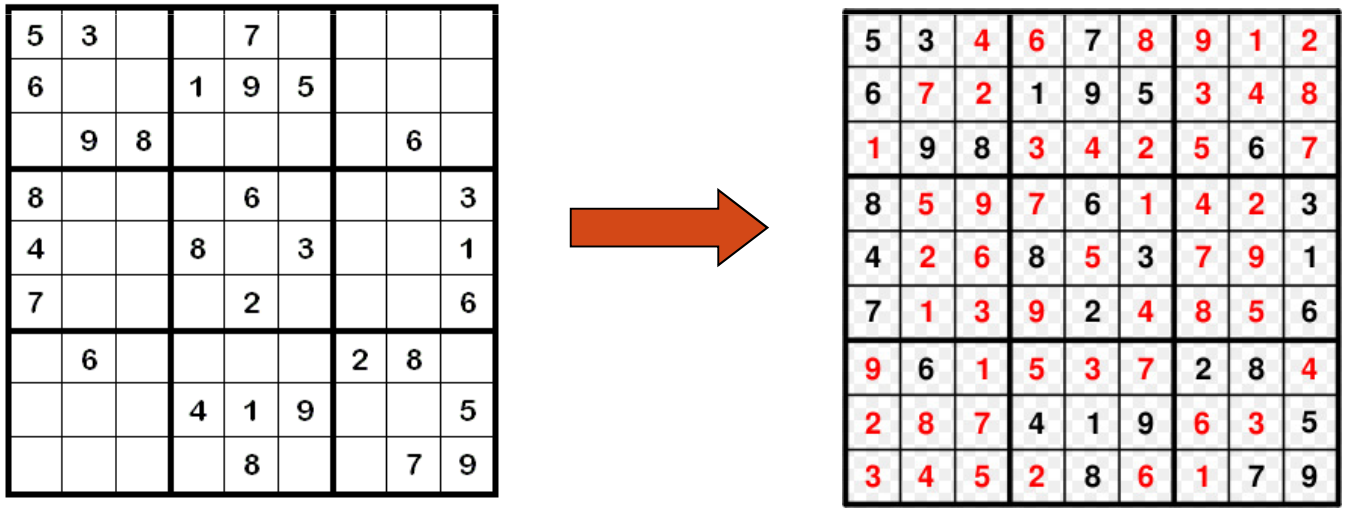
| Methods | Stego image quality (PSNR) | Recovered image quality (PSNR) | Embedding time (sec) | Available embedding capacity (bits) |
|---|---|---|---|---|
| Jo and Kim's ($TH = 40$) | 30.74 | 30.74 | 0.17 | 14,510 |
| Chang and Lin's | 30.23 | 32.24 | 22.59 | 8,098 |
| Proposed ($TH = 40$) | 31.31 | 32.24 | 0.23 | 11,646 |

The comparison using Baboon as the cover image

| Methods | Stego image quality (PSNR) | Recovered image quality (PSNR) | Embedding time (sec) | Available embedding capacity (bits) |
|---|---|---|---|---|
| Jo and Kim's ($TH = 40$) | 24.32 | 24.32 | 0.21 | 10,946 |
| Chang and Lin's | 24.04 | 24.70 | 22.94 | 2,814 |
| Proposed ($TH = 40$) | 24.43 | 24.70 | 0.25 | 8,096 |

# Data hiding using Sudoku (Cont.)

- Spatial domain data embedding
- Sudoku
  - A logic-based number placement puzzle

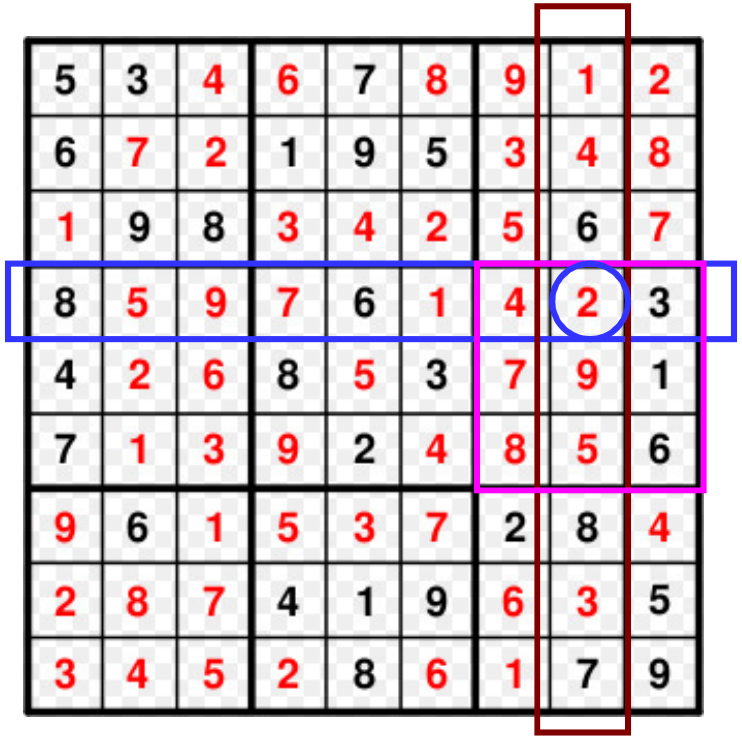


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 | 3 | | | 7 | | | | |
| 6 | | | 1 | 9 | 5 | | | |
| | 9 | 8 | | | | | 6 | |
| 8 | | | | 6 | | | | 3 |
| 4 | | | 8 | | 3 | | | 1 |
| 7 | | | | 2 | | | | 6 |
| | 6 | | | | | 2 | 8 | |
| | | | 4 | 1 | 9 | | | 5 |
| | | | | 8 | | | 7 | 9 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 | 3 | 4 | 6 | 7 | 8 | 9 | 1 | 2 |
| 6 | 7 | 2 | 1 | 9 | 5 | 3 | 4 | 8 |
| 1 | 9 | 8 | 3 | 4 | 2 | 5 | 6 | 7 |
| 8 | 5 | 9 | 7 | 6 | 1 | 4 | 2 | 3 |
| 4 | 2 | 6 | 8 | 5 | 3 | 7 | 9 | 1 |
| 7 | 1 | 3 | 9 | 2 | 4 | 8 | 5 | 6 |
| 9 | 6 | 1 | 5 | 3 | 7 | 2 | 8 | 4 |
| 2 | 8 | 7 | 4 | 1 | 9 | 6 | 3 | 5 |
| 3 | 4 | 5 | 2 | 8 | 6 | 1 | 7 | 9 |

# Data hiding using Sudoku (Cont.)

- Property

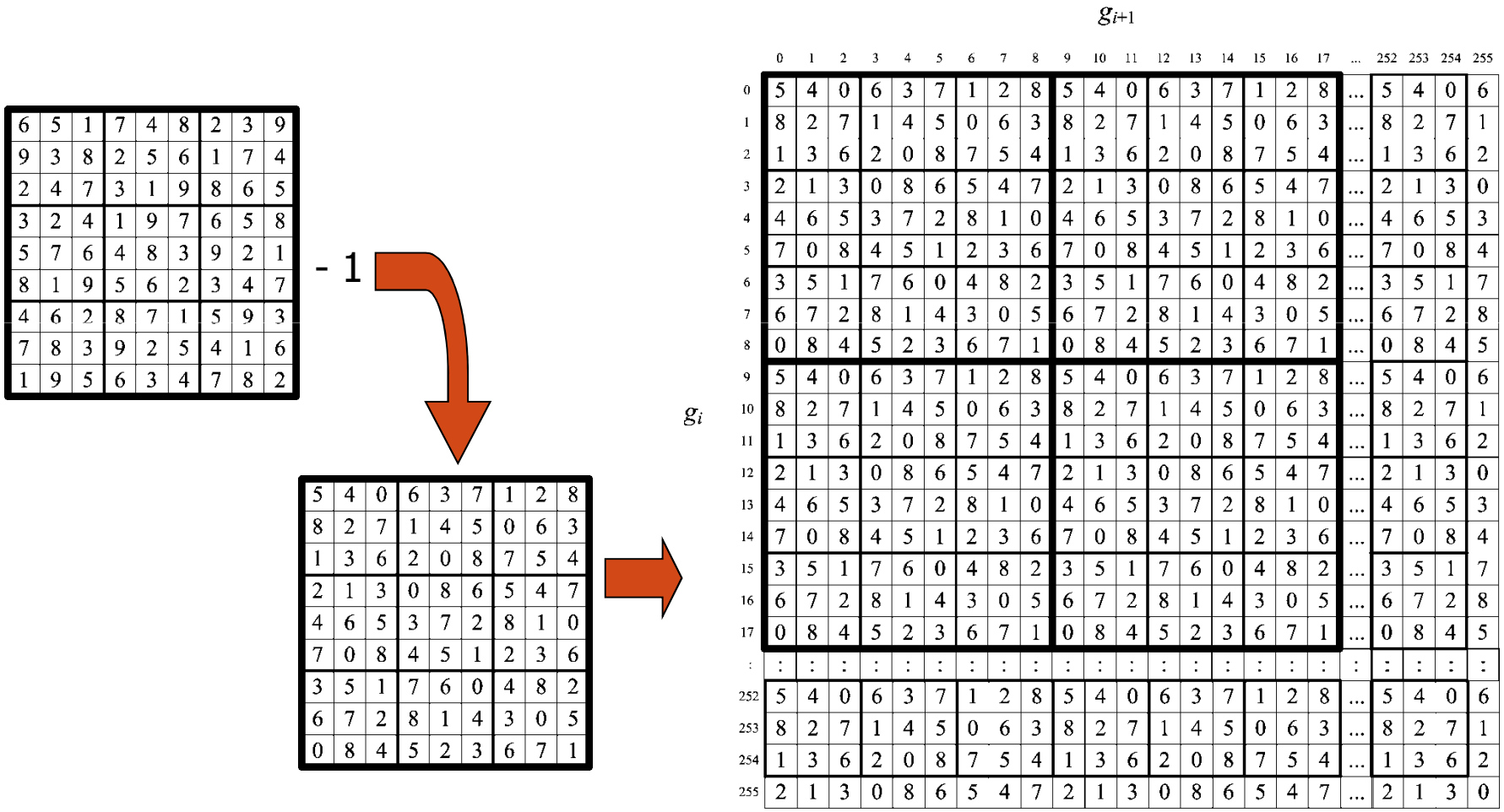


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 | 3 | 4 | 6 | 7 | 8 | 9 | 1 | 2 |
| 6 | 7 | 2 | 1 | 9 | 5 | 3 | 4 | 8 |
| 1 | 9 | 8 | 3 | 4 | 2 | 5 | 6 | 7 |
| 8 | 5 | 9 | 7 | 6 | 1 | 4 | 2 | 3 |
| 4 | 2 | 6 | 8 | 5 | 3 | 7 | 9 | 1 |
| 7 | 1 | 3 | 9 | 2 | 4 | 8 | 5 | 6 |
| 9 | 6 | 1 | 5 | 3 | 7 | 2 | 8 | 4 |
| 2 | 8 | 7 | 4 | 1 | 9 | 6 | 3 | 5 |
| 3 | 4 | 5 | 2 | 8 | 6 | 1 | 7 | 9 |

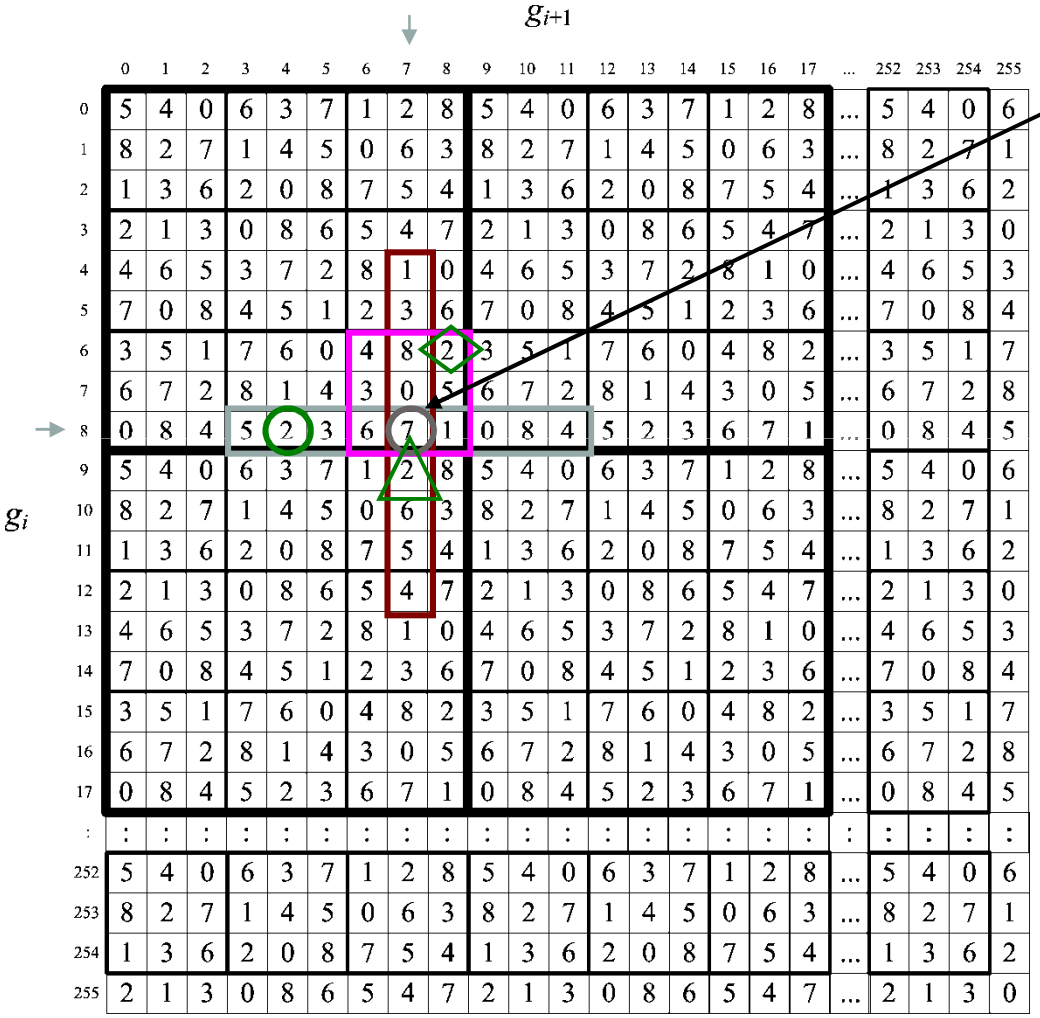
- A Sudoku grid contains nine $3 \times 3$ matrices, each contains different digits from 1 to 9.
- Each row and each column of a Sudoku grid also contain different digits from 1 to 9.

Possible solutions:
6,670,903,752,021,072,936,960
(i.e. $\approx 6.671 \times 10^{21}$)

# Data hiding using Sudoku (Cont.)



# Data hiding using Sudoku (Embedding) (Cont.)




| 8 | 7 | 11 | 12 |
|---|---|---|---|
| 79 | 54 | 55 | 11 |
| 20 | 21 | 12 | 24 |
| 12 | 10 | 10 | 9 |

Cover Image

*Secret data*: 011 001 10…

$27_9$

min.

$d(\bigcirc,\bigcirc) = ((8-8)^2+(4-7)^2)^{1/2}=3$

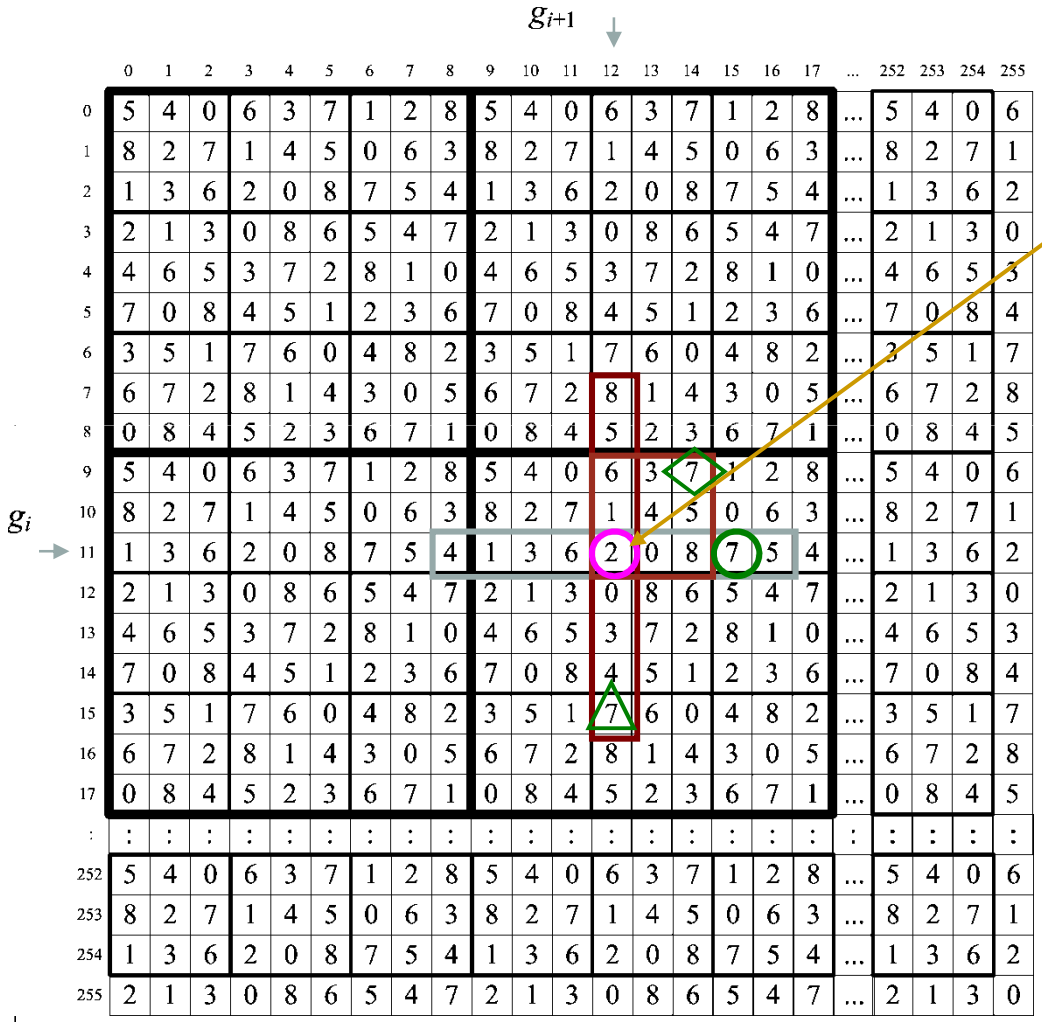
$d(\triangle,\bigcirc) = ((9-8)^2+(7-7)^2)^{1/2}=1$

$d(\diamond,\bigcirc) = ((6-8)^2+(8-7)^2)^{1/2}=2.24$

| 9 | 7 | | |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

Stego Image

# Data hiding using Sudoku (Embedding) (Cont.)




| | | | |
|---|---|---|---|
| 8 | 7 | 11 | 12 |
| 79 | 54 | 55 | 11 |
| 20 | 21 | 12 | 24 |
| 12 | 10 | 10 | 9 |

Cover Image

*Secret data*: 011 001 10…

$27_9$

$d(\bigcirc,\bigcirc) = ((11-11)^2+(15-12)^2)^{1/2}=3$

$d(\triangle,\bigcirc) = ((15-11)^2+(12-12)^2)^{1/2}=4$

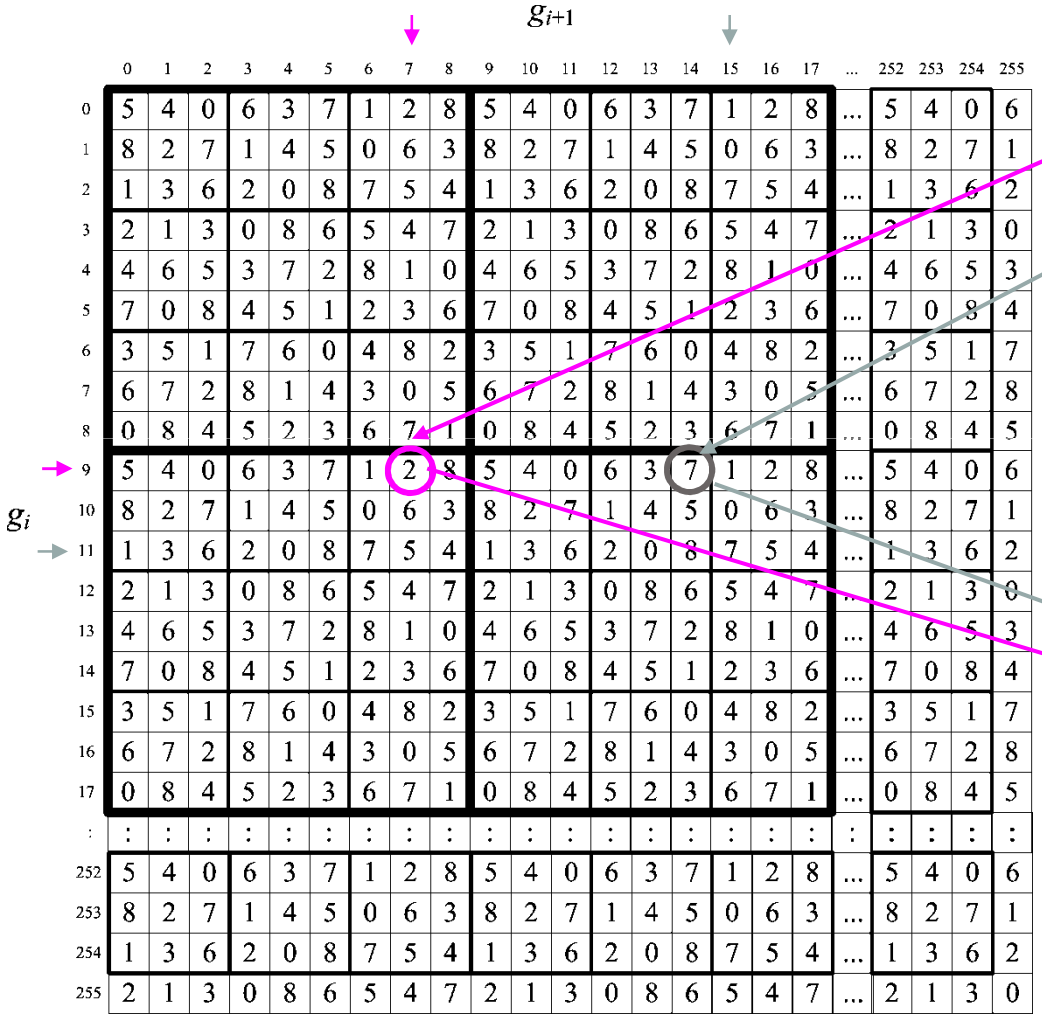
$d(\diamond,\bigcirc) = ((9-11)^2+(14-12)^2)^{1/2}=2.83$

min.

| | | | |
|---|---|---|---|
| 9 | 7 | 9 | 14 |
| | | | |
| | | | |
| | | | |

Stego Image

# Data hiding using Sudoku (Extracting) (Cont.)

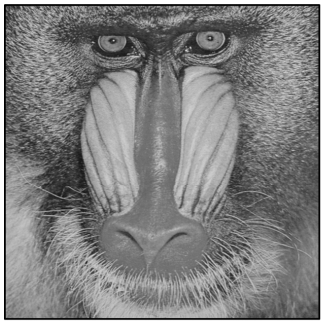



| 9 | 7 | 9 | 14 |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

Stego Image

Extracted data: $27_9 = 011\ 001_2$

# Experimental results



(a) Baboon (*PSNR* = 44.68 dB)

(b) Barbara (*PSNR* = 44.77 dB)

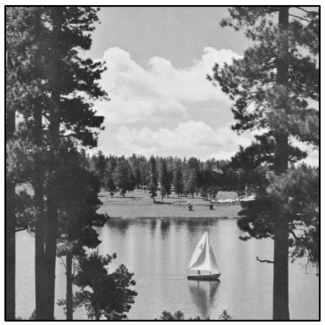
(c) Boat (*PSNR* = 44.94 dB)

(d) Goldhill (*PSNR* = 44.84 dB)


(e) Jet(F16) (*PSNR* = 45.02 dB)

(f) Lena (*PSNR* = 44.97 dB)

(g) Pepper (*PSNR* = 44.67 dB)



(h) Sailboat (*PSNR* = 44.67 dB)

(i) Tiffany (*PSNR* = 45.02 dB)

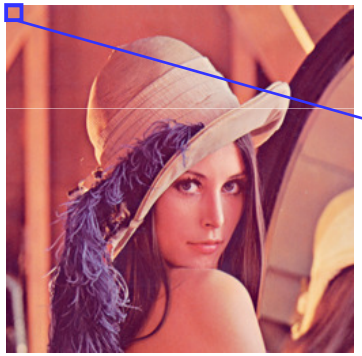
# Experimental results (Cont.)

TABLE I
THE RESULTS OF VISUAL QUALITY AND EMBEDDING CAPACITY COMPARISONS

| Images | Zhang and Wang | | Mielikainen | | Proposed | |
|---|---|---|---|---|---|---|
| | $PSNR$ | $C$ | $PSNR$ | $C$ | $PSNR$ | $C$ |
| Baboon | 52.11 | 1 | 52.76 | 1 | 44.68 | 1.5 |
| Barbara | 52.11 | 1 | 52.77 | 1 | 44.77 | 1.5 |
| Boats | 52.11 | 1 | 52.78 | 1 | 44.94 | 1.5 |
| Goldhill | 52.11 | 1 | 52.77 | 1 | 44.84 | 1.5 |
| Jet(F16) | 52.11 | 1 | 52.77 | 1 | 45.02 | 1.5 |
| Lena | 52.12 | 1 | 52.77 | 1 | 44.97 | 1.5 |
| Pepper | 52.12 | 1 | 52.77 | 1 | 44.67 | 1.5 |
| Sailboat | 52.11 | 1 | 52.75 | 1 | 44.67 | 1.5 |
| Tiffany | 52.11 | 1 | 52.77 | 1 | 45.02 | 1.5 |
| Average | 52.11 | 1 | 52.77 | 1 | 44.88 | 1.5 |

# Data hiding for color images

- True color and color palette image
- Color pixel (Red, Green, Blue)
- Reversibility
- Review Fridrich's method



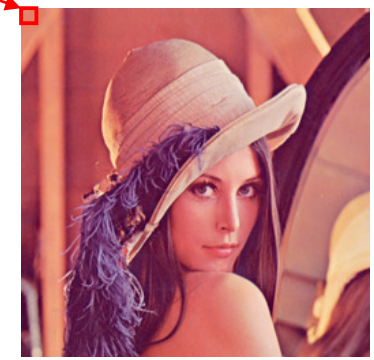
Image

| | |
|---|---|
| 0 | (15, 16, 13) |
| 1 | (35, 26, 42) |
| : | : |
| 127 | (115, 216, 112) |
| 128 | (105, 146, 193) |
| : | : |
| 254 | (223, 216, 232) |
| 255 | (250, 252, 248) |

Sorted color palette

R+G+B mod 2 = (115 + 216 + 112) mod 2 = 1
R+G+B mod 2 = (105 + 146 + 193) mod 2 = 0

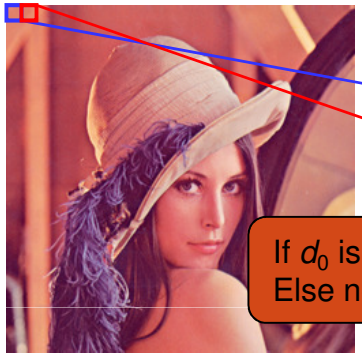
Secret: 010…



Stego

# Data hiding for color images (Cont.)

- Proposed method (Embedding)



Image

( R, G, B)

$p_i$ = (112, 217, 110)

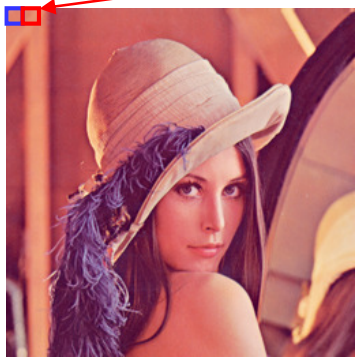
$p_{i+1}$=(115, 216, 112)

(115, 216, 112)
(115, 112, 216)
(216, 115, 112)
(216, 112, 115)
(112, 115, 216)
(112, 216, 115)

$d_0$ = 3.74
$d_1$ = 149.23
$d_2$ = 145.68
$d_3$ = 147.87
$d_4$ = 147.11
$d_5$ = 5.1

If $d_0$ is first one then embeddable
Else non-embeddable

Sorting



Stego

00 01 10 11

$d_0 < d_5 < d_4 < d_3 < d_2 < d_1$

$\lfloor \log_2 N_G \rfloor = \lfloor \log_2 6 \rfloor = 2$

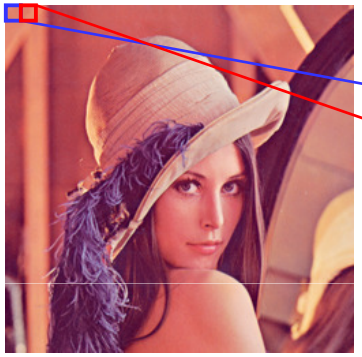
Secret: 011…

If $d(p_{i+1}, p'_{i+1}) < TH=50$ then embed secret
Else non-embeddable

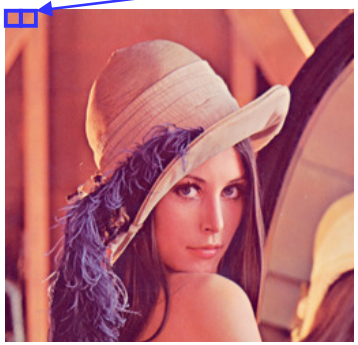
require extra information

# Data hiding for color images (Cont.)

- Proposed method (Extracting and restoring)



Stego



Restored image

( R, G, B)
(112, 217, 110)
(112, 216, 115)

(112, 216, 115)
(112, 115, 216)
(216, 112, 115)
(216, 115, 112)
(115, 112, 216)
(115, 216, 112)

$d_0 = 5.1$
$d_1 = 147.11$
$d_2 = 147.87$
$d_3 = 145.68$
$d_4 = 149.23$
$d_5 = 3.74$

Sorting

00 01 10 11

$d_5 < d_0 < d_3 < d_1 < d_2 < d_4$

$\lfloor \log_2 N_G \rfloor = \lfloor \log_2 6 \rfloor = 2$

Extracted data: 01

# Data hiding for color images (Cont.)

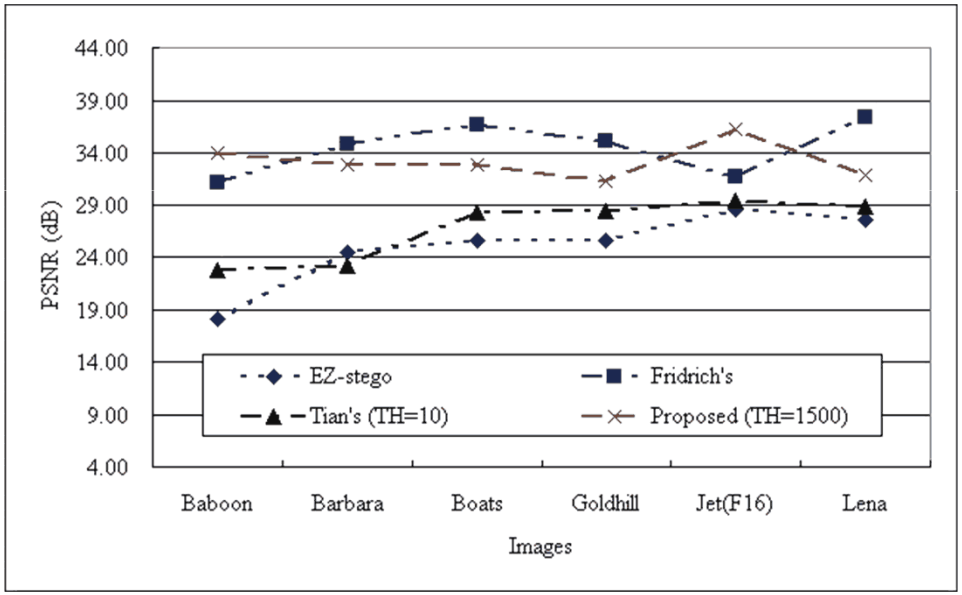
- Experimental results

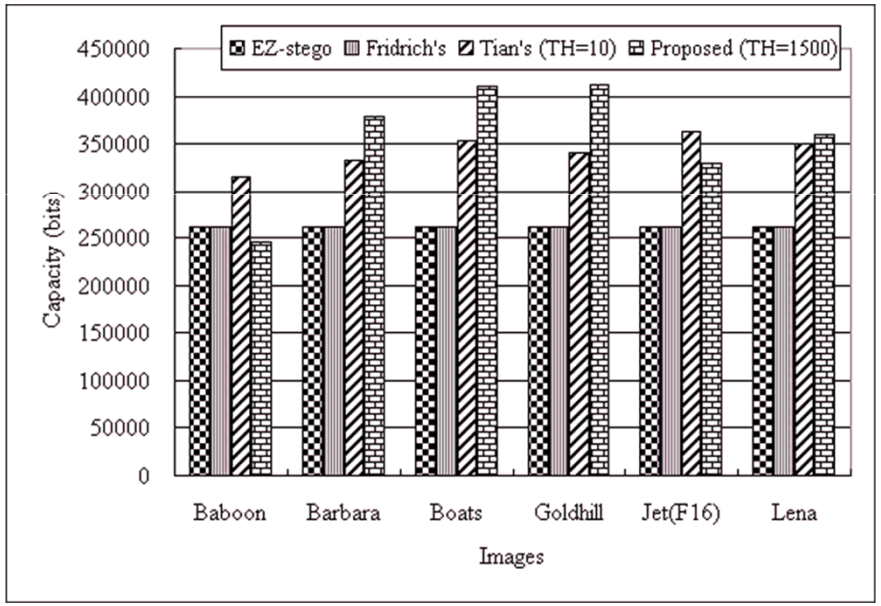
(a) EZ-stego (b) Fridrich's method

(c) Tian's method ($TH$=10) (d) Proposed method ($TH$=1500)

# Data hiding for color images (Cont.)

- Experimental results



# High payload data hiding for color images

- Review Tzeng's method

| | | | |
|---|---|---|---|
| (10, 20, 15) | (6, 8, 15) | (10, 10, 12) | ... |
| (12, 18, 9) | (16, 18, 25) | ... | ... |
| : | : | | |

Image

$v = 0.3 \times r + 0.59 \times g + 0.11 \times b$

$v_1 = 0.3 \times 10 + 0.59 \times 20 + 0.11 \times 15 = 16.45$

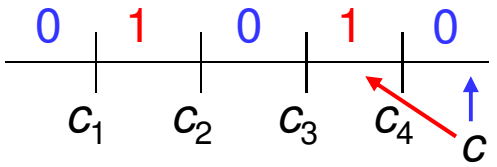
$v_2 = 8.17$

$v_3 = 10.22$

$v_4 = 15.21$

$v_c = 18.17$

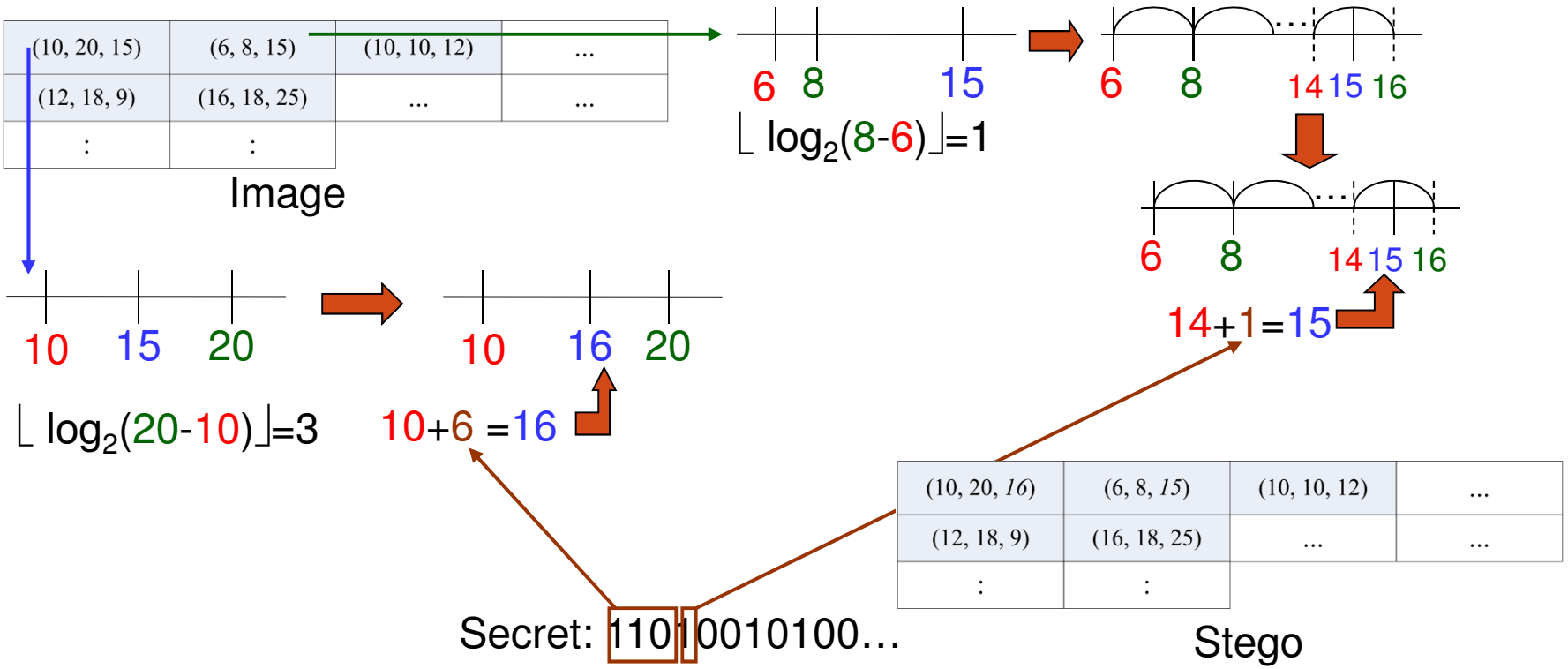
$c_1 > c_2$, if ($v_1 > v_2$) or
($v_1 = v_2$ and $r_1 > r_2$) or
($v_1 = v_2$ and $r_1 = r_2$ and $g_1 > g_2$)
$c_1 = c_2$, if ($r_1 = r_2$ and $g_1 = g_2$ and $g_1 = g_2$)
$c_1 < c_2$, otherwise




Secret: 101…

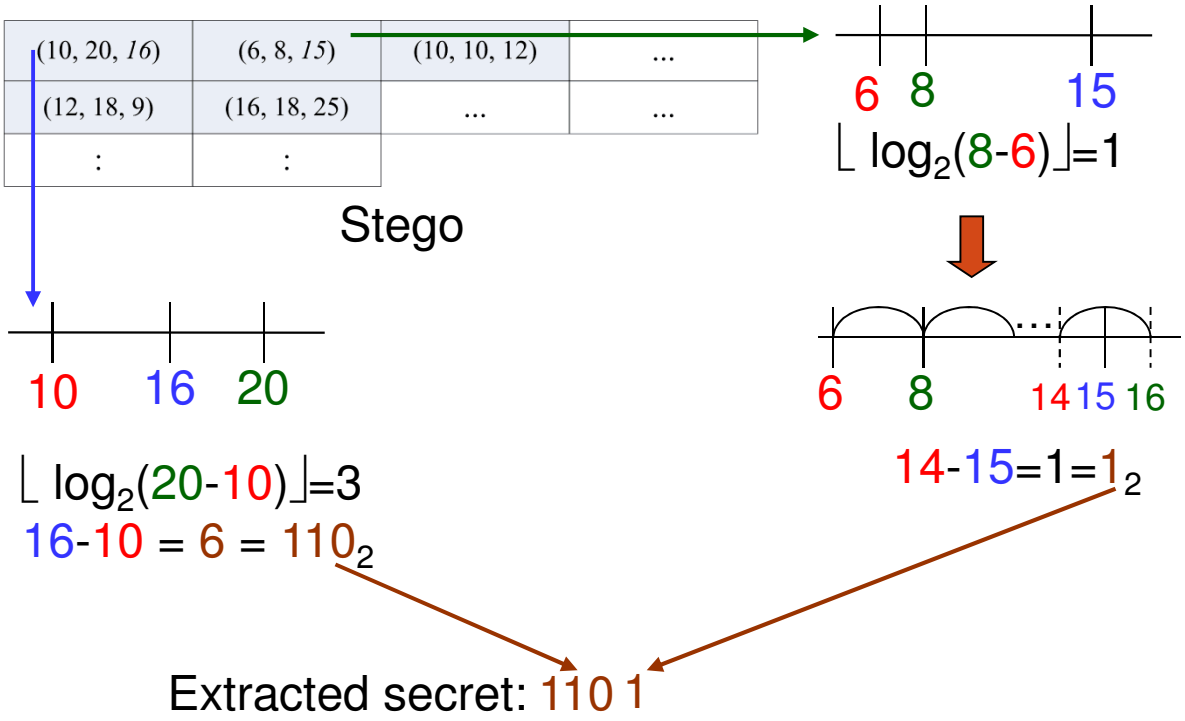
# High payload data hiding for color images (Cont.)

- The proposed (Embedding)



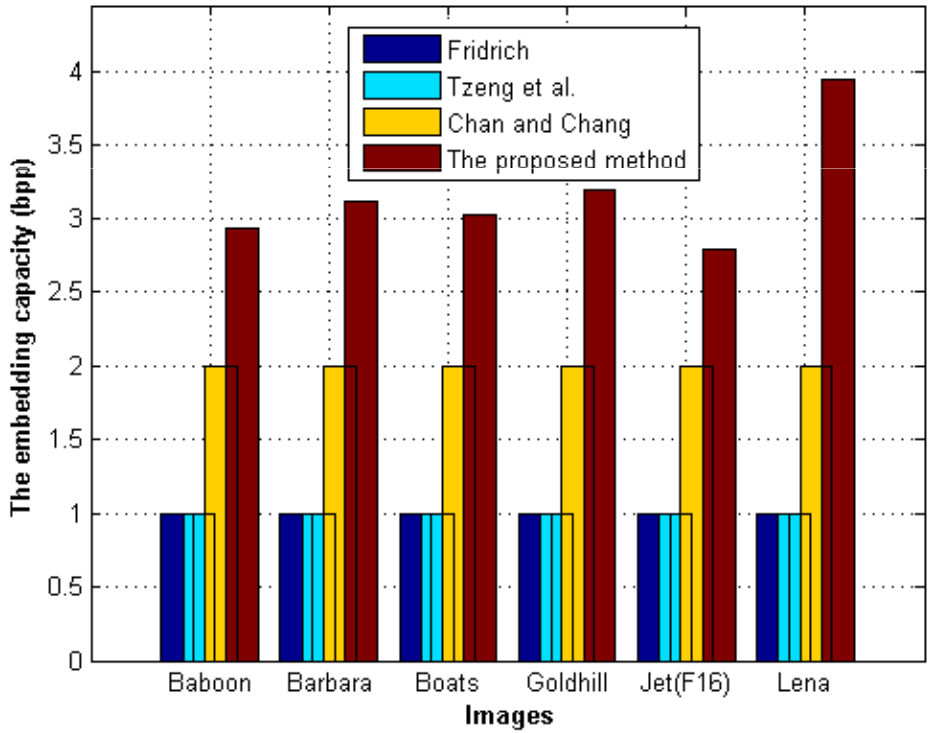
# High payload data hiding for color images (Cont.)

- The proposed (Extracting)



# High payload data hiding for color images (Cont.)

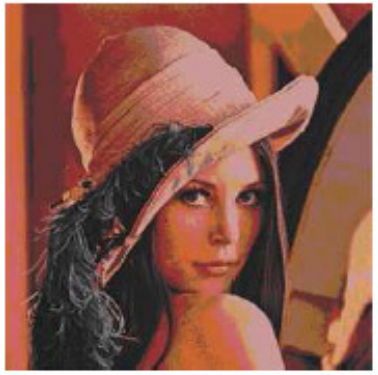
- Experimental results



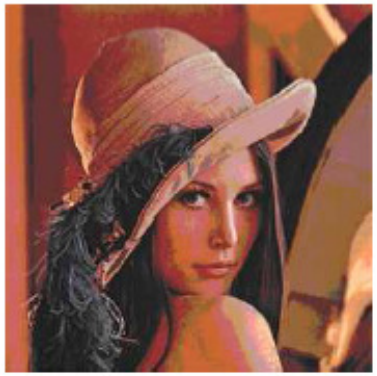
# High payload data hiding for color images (Cont.)

(a) Original Lena image

(b) The proposed Method (TH = 100), PSNR = 76.486 dB, $C$ = 3.949 bpp



(c) Fridrich's method PSNR= 31.826 dB, $C$ = 1 bpp

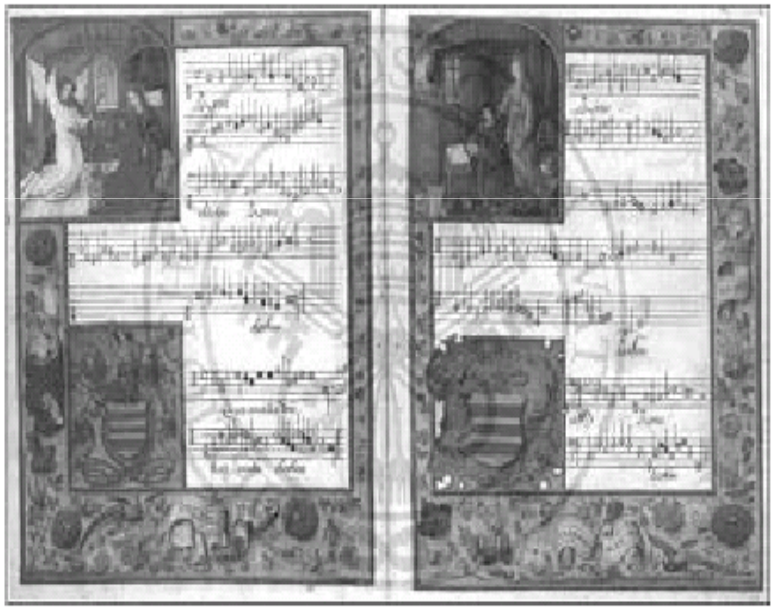


(d) Tzeng et al.'s method, PSNR= 33.283 dB, C = 0.996 bpp

(e) Chan and Chang's method, PSNR= 28.346 dB, C = 1.992 bpp

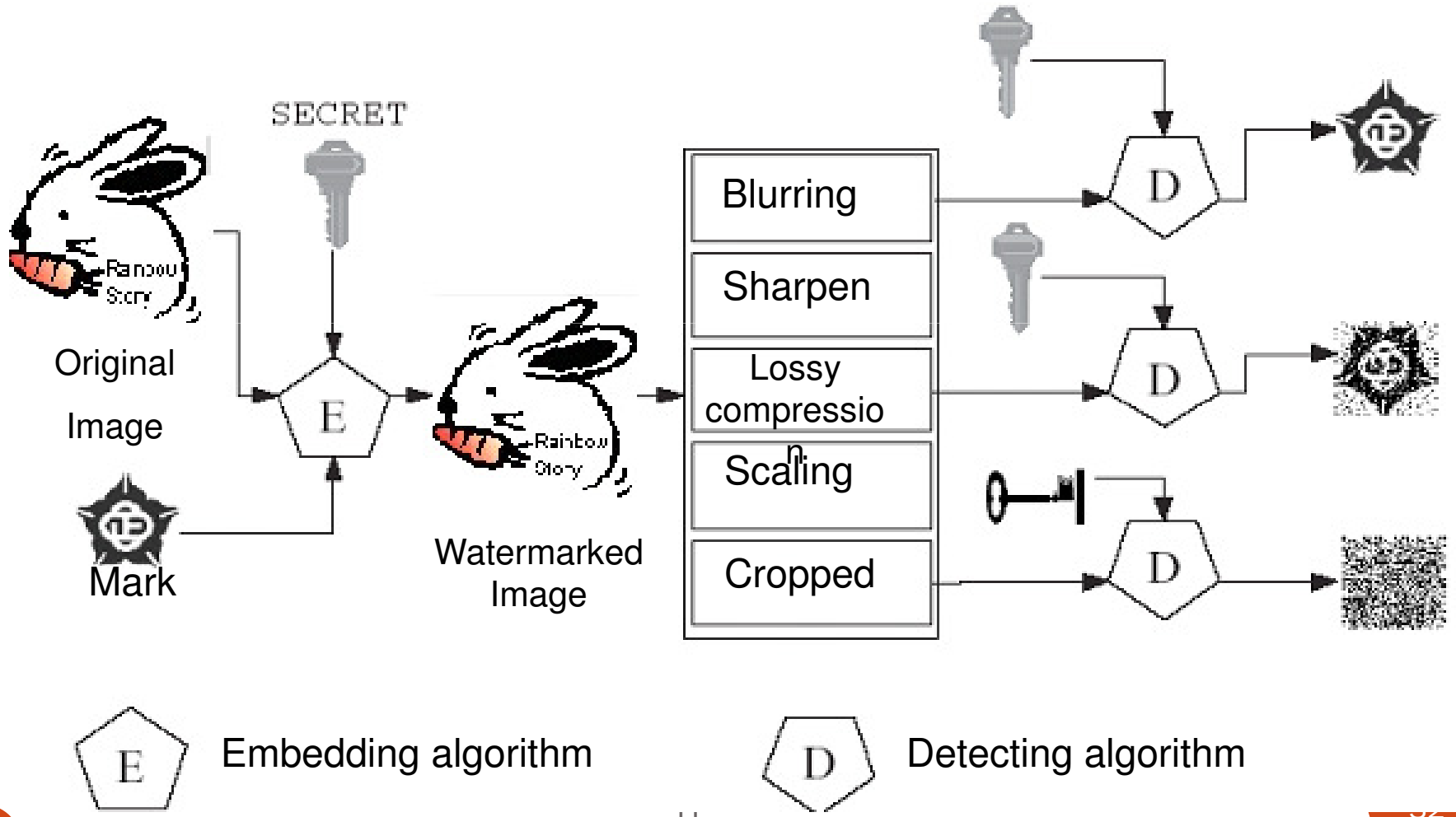
# Digital Image Copyright Protection

Visible



Invisible

# Digital Image Copyright Protection (Cont.)

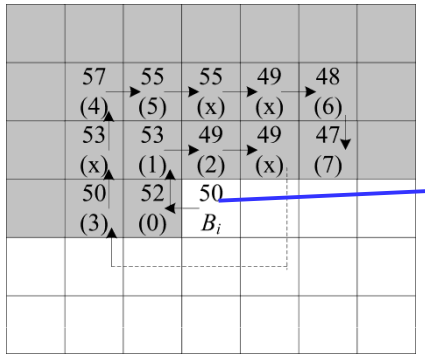


# Digital Image Copyright Protection (Cont.)

- Watermarking characteristics:
  - Invisibility
  - Security
  - Blindness
  - Multiple Watermarks
  - Robustness

# SOC improvement

- Scan-order coding (SOC)



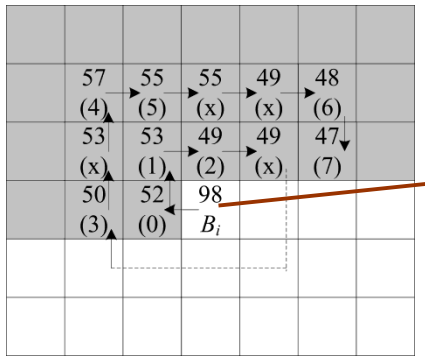

Index table

| | |
|---|---|
| 0 | 52 |
| 1 | 53 |
| 2 | 49 |
| 3 | 50 |
| 4 | 57 |
| 5 | 55 |
| 6 | 48 |
| 7 | 47 |

State codebook

Indicator

Compression code: …1 011…




Index table

| | |
|---|---|
| 0 | 52 |
| 1 | 53 |
| 2 | 49 |
| 3 | 50 |
| 4 | 57 |
| 5 | 55 |
| 6 | 48 |
| 7 | 47 |

State codebook

Indicator

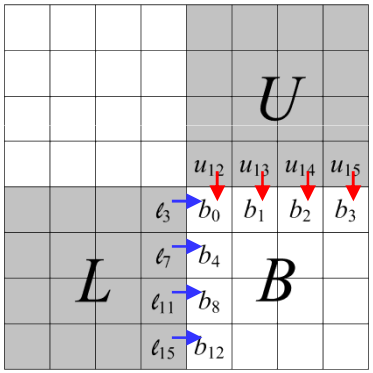
Compression code: …0 01100010…

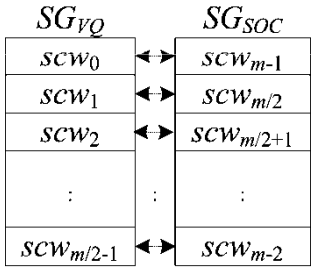
# SOC improvement (Cont.)

- Review Lin and Chang's method

$$SMD(cw_x, NBV_{B_i}) = \sqrt{\sum_{j=0,1,2,3,4,8,12} (cw_x(j) - NBV_{B_i}(j))^2}$$

$NBV_B = \{b_0, b_1, b_3, b_4, X, X, X, b_8, X, X, X, b_{12}, X, X, X\}$




If $SMD(\alpha, NBV_B) < SMD(\overline{\alpha}, NBV_B)$

Secret = 0 ⇒ $\alpha$

Secret = 1 ⇒ $\overline{\alpha}$

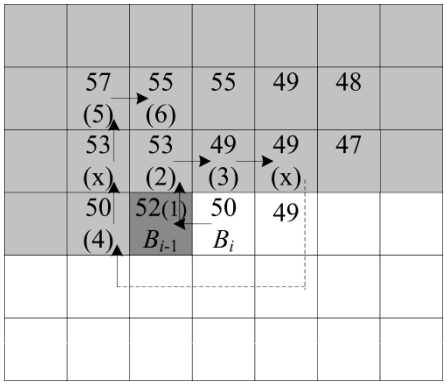
If $SMD(\alpha, NBV_B) \geq SMD(\overline{\alpha}, NBV_B)$

Secret = 0 ⇒ $000 \| \alpha$

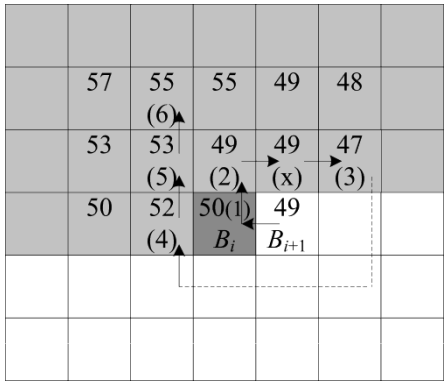
Secret = 1 ⇒ $111 \| \alpha$

# SOC improvement (Cont.)

- The proposed method (Encoding)




Index table




Index table

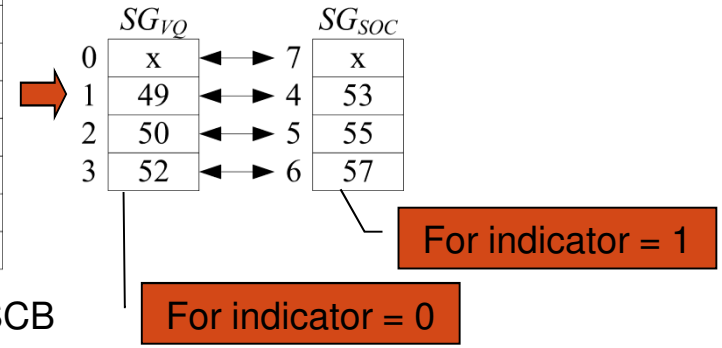
| | |
|---|---|
| 0 | x |
| 1 | 47 |
| 2 | 49 |
| 3 | 50 |
| 4 | 52 |
| 5 | 53 |
| 6 | 55 |
| 7 | x |

Sorted SCB

Can be compressed by SOC (i.e. indicator = 1)

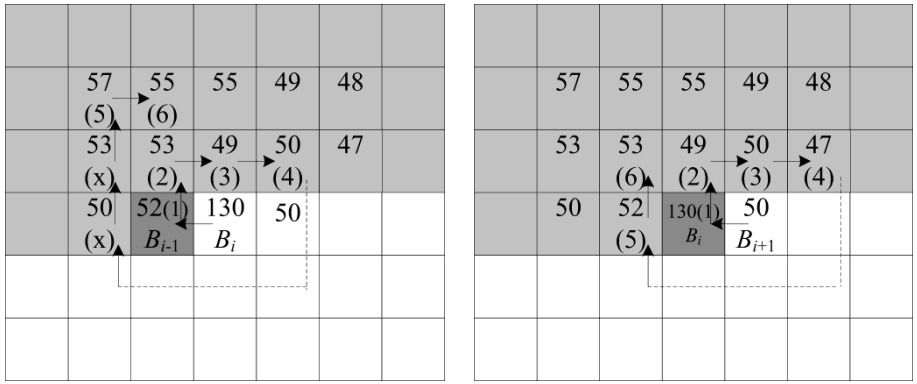
| | |
|---|---|
| 0 | x |
| 1 | 49 |
| 2 | 50 |
| 3 | 52 |
| 4 | 53 |
| 5 | 55 |
| 6 | 57 |
| 7 | x |

Sorted SCB




If $SMD(cw_{50}, NBV_{B_i}) < SMD(cw_{55}, NBV_{B_i})$
Compression code: …101
Else Compression code: … 111 010

# SOC improvement (Cont.)




Index table

Index table

Can be compressed by SOC (i.e. indicator = 1)

| | $MG_{VQ}$ | $MG_{SOC}$ |
|---|---|---|
| | 0 | 255 |
| | 1 | 128 |
| | 2 | 129 |
| | 3 | 130 |
| | : | : |
| | 127 | 254 |

For indicator = 1

For indicator = 0

| | Sorted SCB |
|---|---|
| 0 | x |
| 1 | 49 |
| 2 | 50 |
| 3 | 52 |
| 4 | 53 |
| 5 | 55 |
| 6 | 57 |
| 7 | x |

| | $SG_{VQ}$ | | $SG_{SOC}$ |
|---|---|---|---|
| 0 | x | 7 | x |
| 1 | 49 | 4 | 53 |
| 2 | 50 | 5 | 55 |
| 3 | 52 | 6 | 57 |

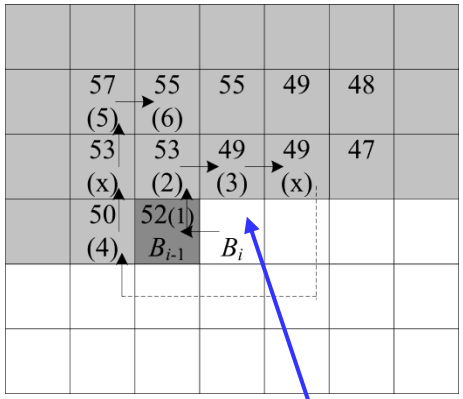
For indicator = 1

For indicator = 0

If $SMD(cw_{130}, NBV_{B_i}) < SMD(cw_3, NBV_{B_i})$
Compression code: … 10000010
Else Compression code: … 11111111 10000010

# SOC improvement (Cont.)

- The proposed method (Decoding)



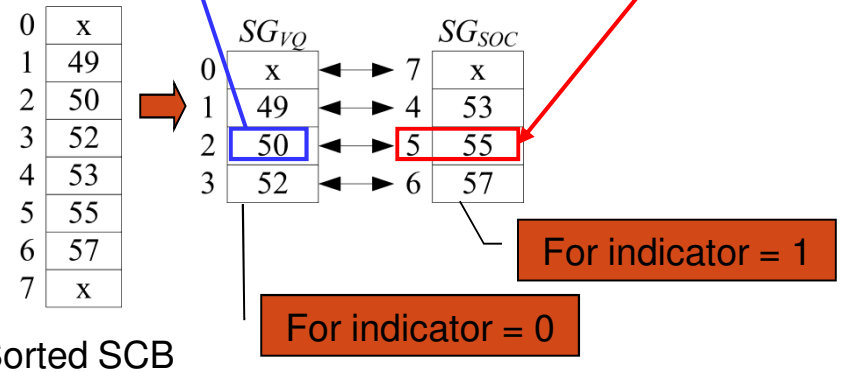

Compression code: …101…

The indicator for next block is '1'

$SMD(cw_{55}, NBV_{B_i}) \geq SMD(cw_{50}, NBV_{B_i})$

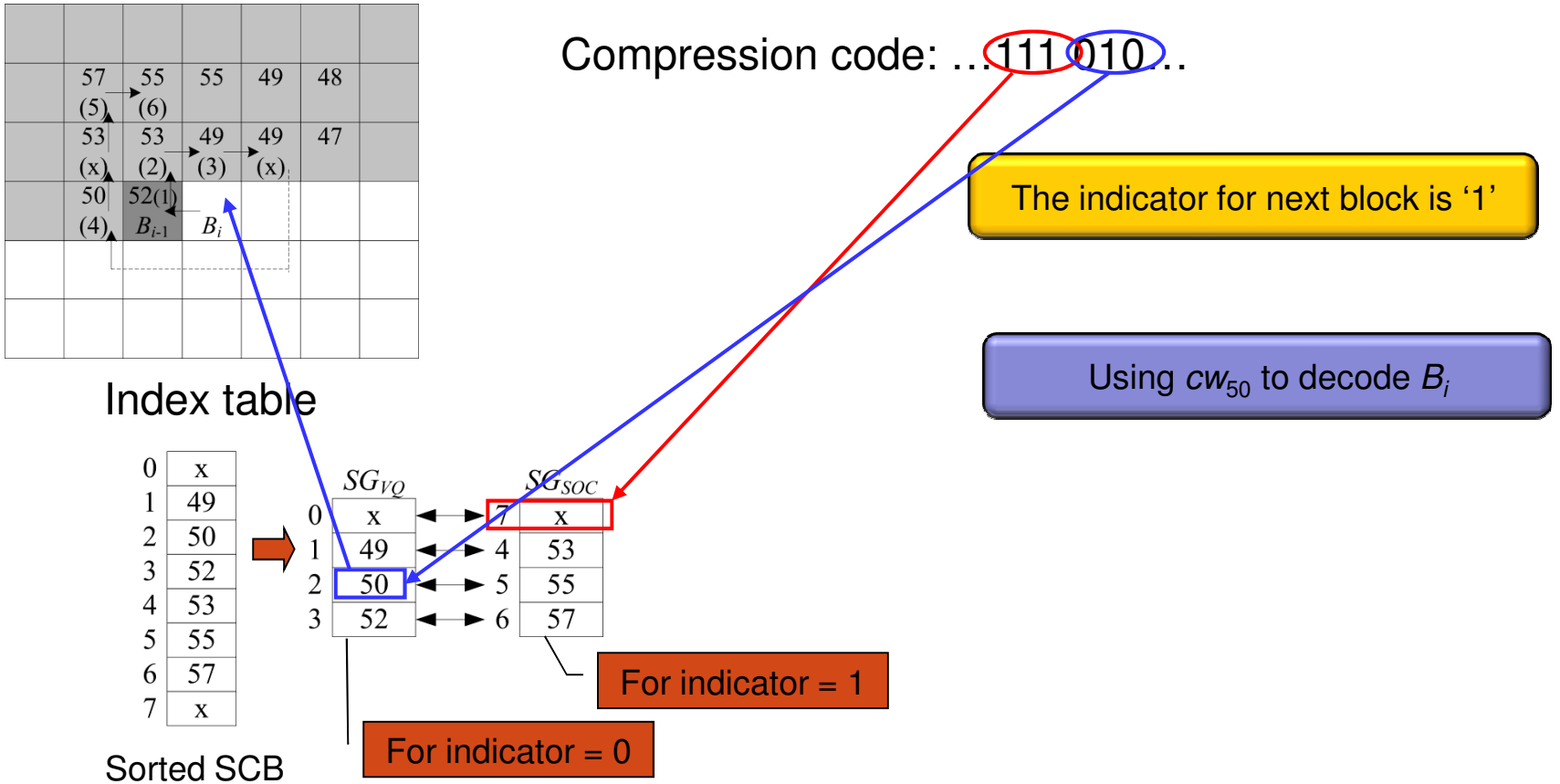
Using $cw_{50}$ to decode $B_i$

Index table




Sorted SCB

# SOC improvement (Cont.)



# SOC improvement (Cont.)

| Relationship | | $SMD$ function: $SMD(t_i, NBV_{B_i}) < SMD(\overline{t_i}, NBV_{B_i})$ | $SMD$ function: $SMD(t_i, NBV_{B_i}) \geq SMD(\overline{t_i}, NBV_{B_i})$ |
|---|---|---|---|
| $t_i \in G_{VQ}$ | $p_{i+1} = 0$ | $t_i$ | $0 \| \| t_i$ |
| | $p_{i+1} = 1$ | $\overline{t_i}$ | $n-1 \| \| t_i$ |
| $t_i \in G_{SOC}$ | $p_{i+1} = 0$ | $\overline{t_i}$ | $0 \| \| t_i$ |
| | $p_{i+1} = 1$ | $t_i$ | $n-1 \| \| t_i$ |

| Relationship | | $SMD$ function: $SMD(SCB(t_i), NBV_{B_i}) < SMD(SCB(\overline{t_i}), NBV_{B_i})$ | $SMD$ function: $SMD(SCB(t_i), NBV_{B_i}) \geq SMD(SCB(\overline{t_i}), NBV_{B_i})$ |
|---|---|---|---|
| $t_i \in SG_{VQ}$ | $p_{i+1} = 0$ | $t_i$ | $0 \| \| t_i$ |
| | $p_{i+1} = 1$ | $\overline{t_i}$ | $m-1 \| \| t_i$ |
| $t_i \in SG_{SOC}$ | $p_{i+1} = 0$ | $\overline{t_i}$ | $0 \| \| t_i$ |
| | $p_{i+1} = 1$ | $t_i$ | $m-1 \| \| t_i$ |

# SOC improvement (Cont.)

- Experimental results

| Images | | Codebook size $m=4$ | $m=8$ | $m=16$ |
|---|---|---|---|---|
| Baboon | RBR(%) | 3.62 | 6.66 | 9.28 |
| | Time(sec.) | 0.031 | 0.047 | 0.109 |
| | PSNR (dB) | 24.7 | 24.7 | 24.7 |
| Jet(F16) | RBR (%) | 23.39 | 29.87 | 30.82 |
| | Time (sec.) | 0.015 | 0.078 | 0.125 |
| | PSNR (dB) | 31.58 | 31.58 | 31.58 |
| Lena | RBR (%) | 20.92 | 27.53 | 29.44 |
| | Time (sec.) | 0.031 | 0.078 | 0.141 |
| | PSNR (dB) | 32.24 | 32.24 | 32.24 |
| Pepper | RBR (%) | 22.46 | 28.33 | 29.41 |
| | Time (sec.) | 0.032 | 0.078 | 0.141 |
| | PSNR (dB) | 30.47 | 30.47 | 30.47 |
| Sailboat | RBR (%) | 18.38 | 24.33 | 25.24 |
| | Time (sec.) | 0.015 | 0.062 | 0.141 |
| | PSNR (dB) | 27.15 | 27.15 | 27.15 |
| Tiffany | RBR (%) | 35.37 | 43.17 | 40.37 |
| | Time (sec.) | 0.032 | 0.094 | 0.156 |
| | PSNR (dB) | 29.57 | 29.57 | 29.57 |
| Average RBR (%) | | 20.69 | 26.65 | 27.43 |
| Average time (sec.) | | 0.03 | 0.07 | 0.14 |
| Average PSNR (dB) | | 29.29 | 29.29 | 29.29 |

| Images | | Conditions IESOC | SOC | LAS | SMVQ |
|---|---|---|---|---|---|
| Baboon | RBR (%) | 9.28 | 4.15 | -2.37 | 10.79 |
| | Time (sec.) | 0.109 | 0.093 | 3.719 | 7.969 |
| | PSNR (dB) | 24.7 | 24.7 | 24.7 | 24.7 |
| Jet(F16) | RBR (%) | 30.82 | 22.5 | 18.17 | 31.89 |
| | Time (sec.) | 0.125 | 0.094 | 2.406 | 12.265 |
| | PSNR (dB) | 31.58 | 31.58 | 31.58 | 31.57 |
| Lena | RBR (%) | 29.44 | 21.39 | 13.73 | 32.3 |
| | Time (sec.) | 0.141 | 0.109 | 2.547 | 7.547 |
| | PSNR (dB) | 32.24 | 32.24 | 32.24 | 32.23 |
| Pepper | RBR (%) | 29.41 | 20.85 | 15.79 | 33.45 |
| | Time (sec.) | 0.141 | 0.11 | 2.484 | 7.156 |
| | PSNR (dB) | 30.47 | 30.47 | 30.47 | 30.46 |
| Sailboat | RBR (%) | 25.24 | 18.4 | 14.9 | 27.53 |
| | Time (sec.) | 0.141 | 0.093 | 2.156 | 7.609 |
| | PSNR (dB) | 27.15 | 27.15 | 27.15 | 27.15 |
| Tiffany | RBR (%) | 40.37 | 31.63 | 34.68 | 36.41 |
| | Time (sec.) | 0.156 | 0.109 | 1.875 | 13.609 |
| | PSNR (dB) | 29.57 | 29.57 | 29.57 | 29.57 |
| Average RBR (%) | | 27.43 | 19.82 | 15.82 | 28.73 |
| Average time (sec.) | | 0.14 | 0.1 | 2.53 | 9.36 |
| Average PSNR (dB) | | 29.29 | 29.29 | 29.29 | 29.28 |