

Removable Digital Watermarking and Image Protection Mechanisms

可移除式數位浮水印及影像保護機制

Advisor: Prof. Chin-Chen Chang

Student: Pei-Yu Lin

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Outline

Part I: Robust Watermarking

- Protect the intellectual property rights, copyright, and ownership
 - Digital Watermarking Scheme for Lossless Images
 - ✓ Digital Watermarking Scheme for Removable Images

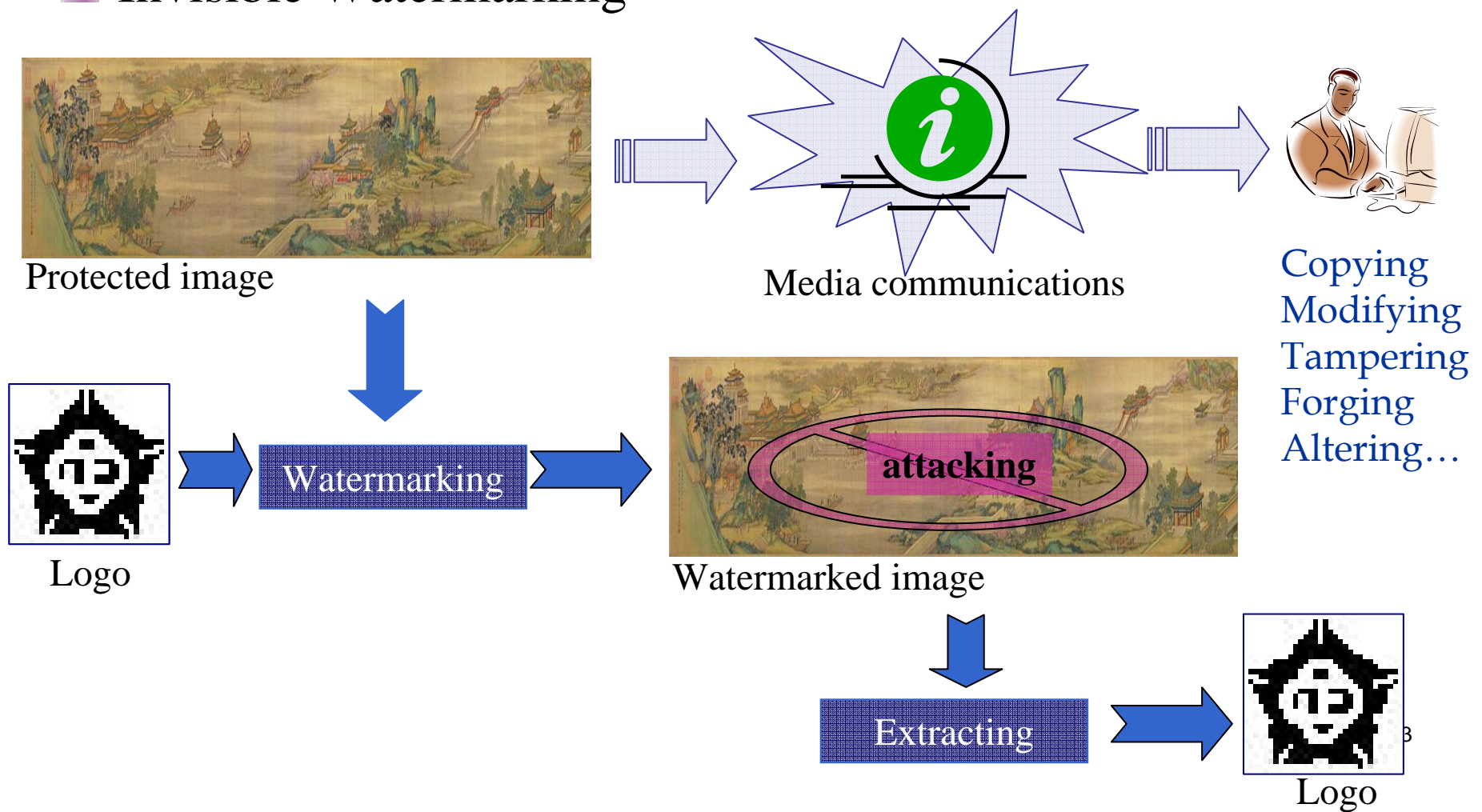
Part II: Image Authentication

- Protect the integrity of image content
 - Image Authentication Scheme for Digital Images
 - ✓ Image Authentication Scheme for Palette-based Color Images



The Fields of Robust Watermarking

- Visible Watermarking
- Invisible Watermarking



Invisible Watermarking

- Protect the copyright without revealing the logo
- Require the fidelity of watermarked image
- Robust to resist malicious attacks



Protected image

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Copyright © National Palace Museum
All Rights Reserved

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Watermarked image

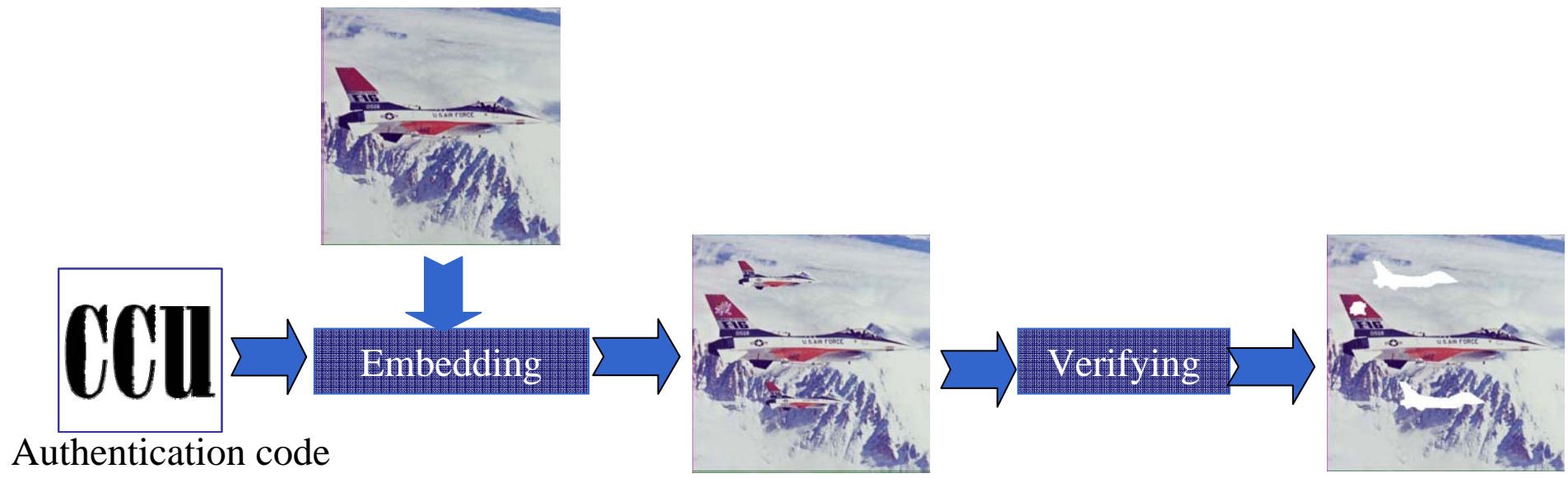
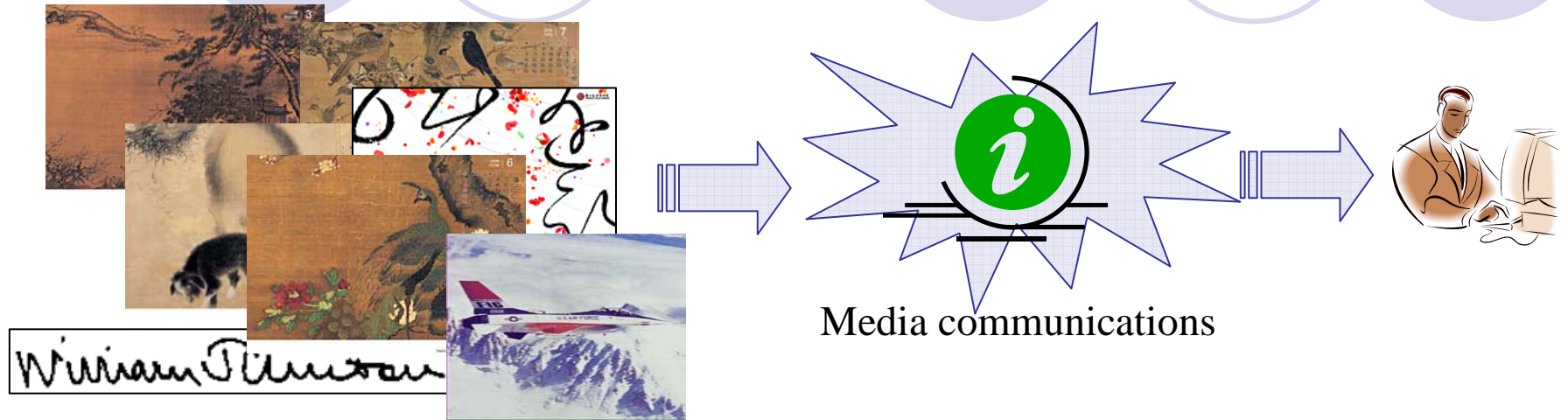
Visible Watermarking

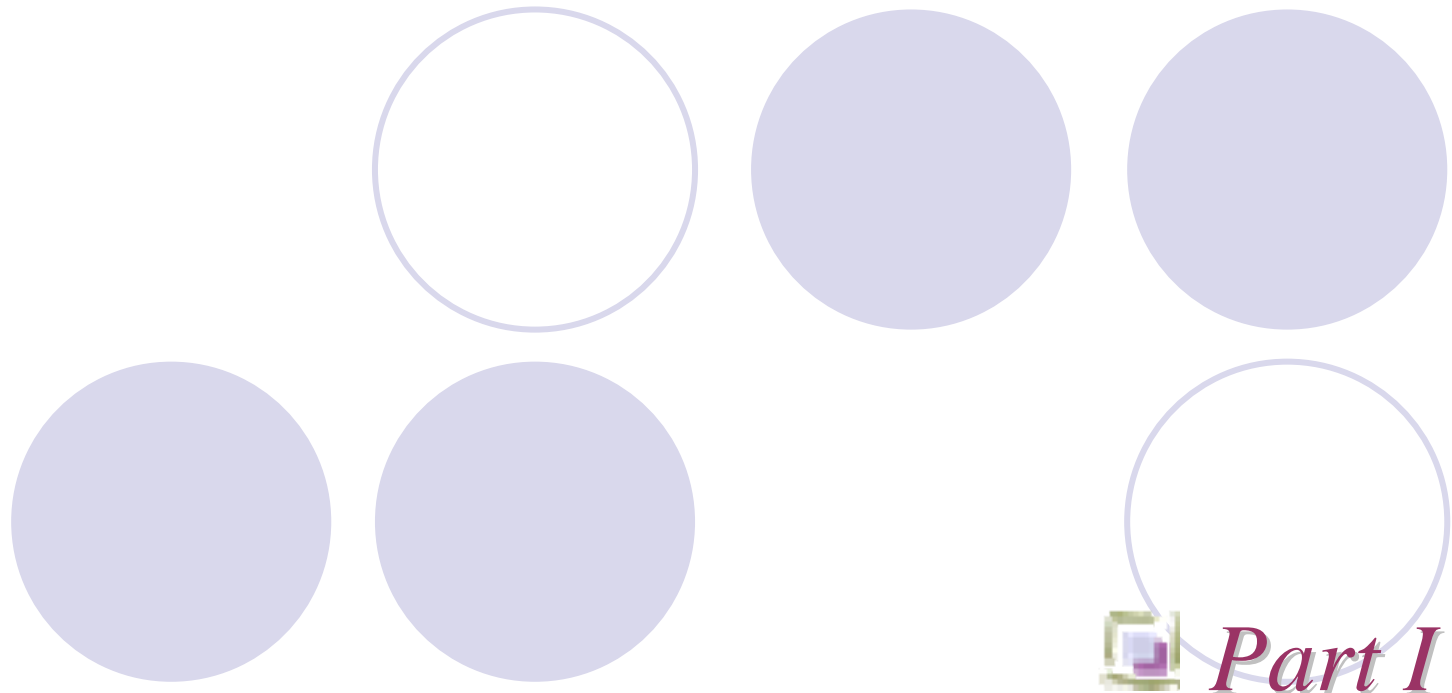
- Exhibit the embedded logo from the multimedia
- Recognize the ownership of the content through visual perception
- Vulnerable to inpainting attack

此處有可視浮水印



The Fields of Image Authentication



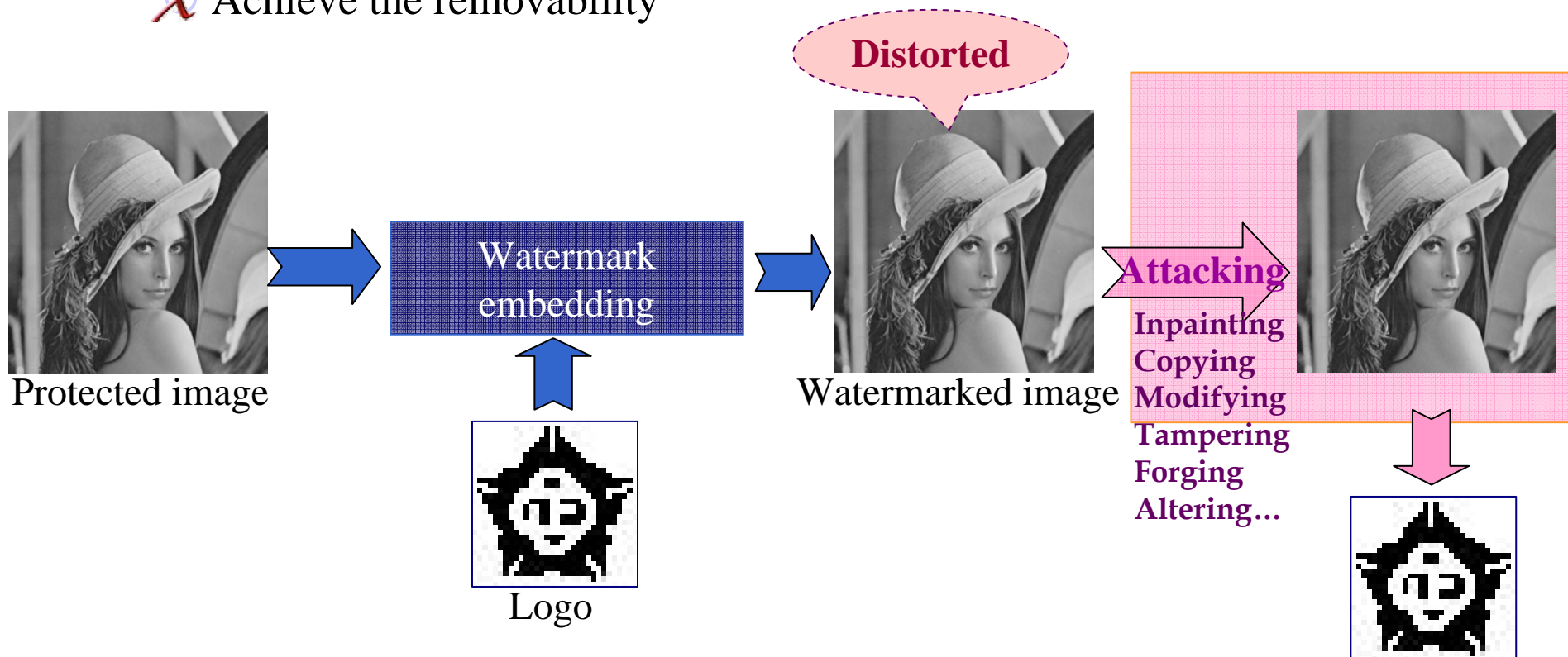


 *Part I*

Digital Watermarking Scheme for Removable Images

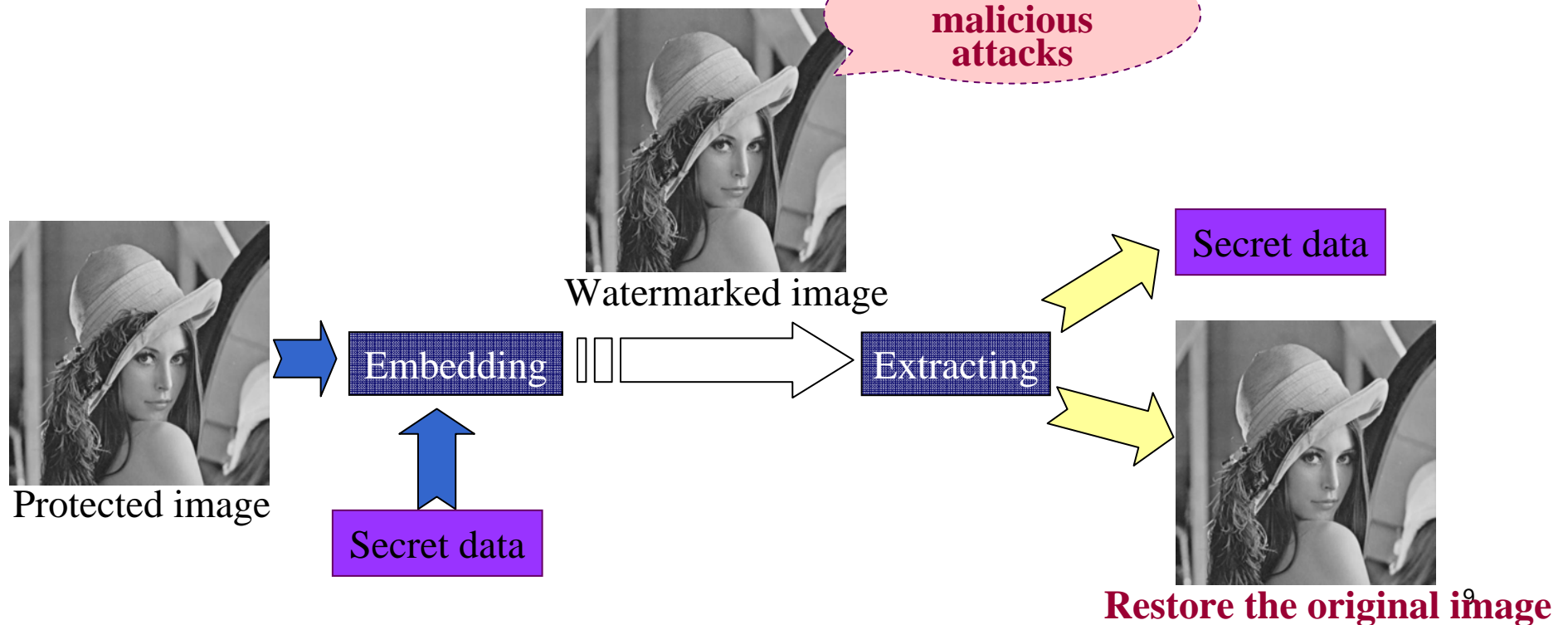
Requirements of Robust Watermarking

- Traditional Robust Watermarking
 - Preserve the quality of the watermarked image
 - Resist the malicious attacks
 - ~~X~~ Protect the content of artistic images, and valuable images
 - ~~X~~ Achieve the removability



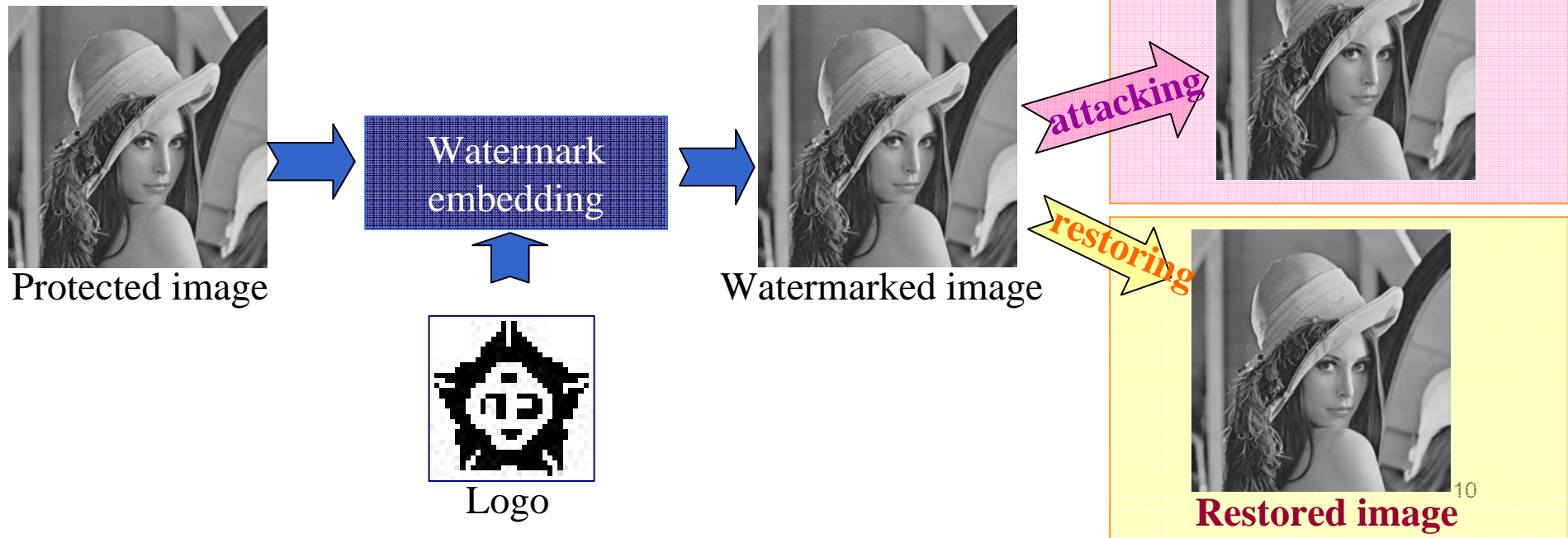
Reversible / Removability

- Remove the embedded data to restore the original image.
- Preserve the fidelity of military and medical image
- ~~X~~ Resist the malicious attacks

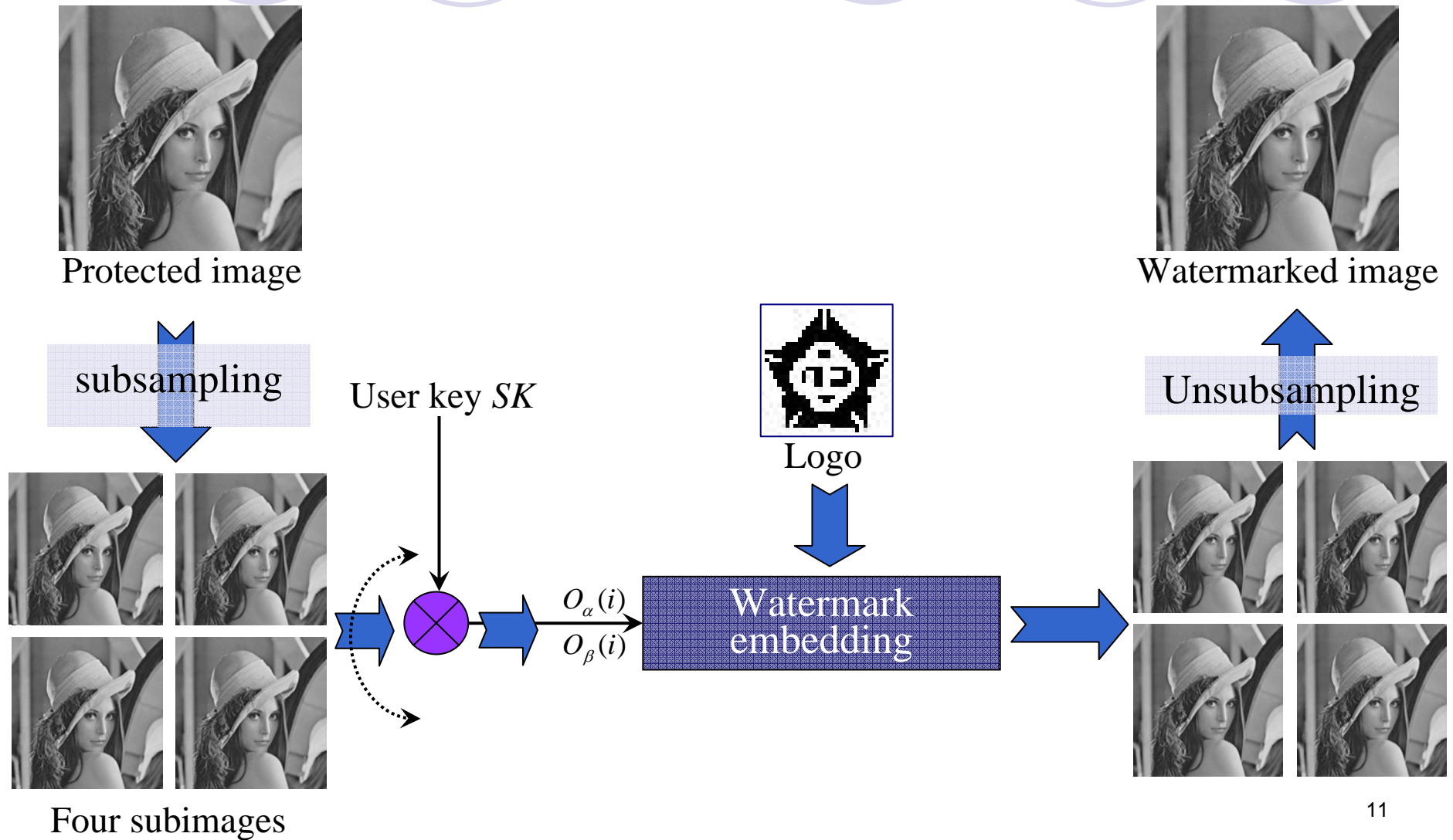


Motivation

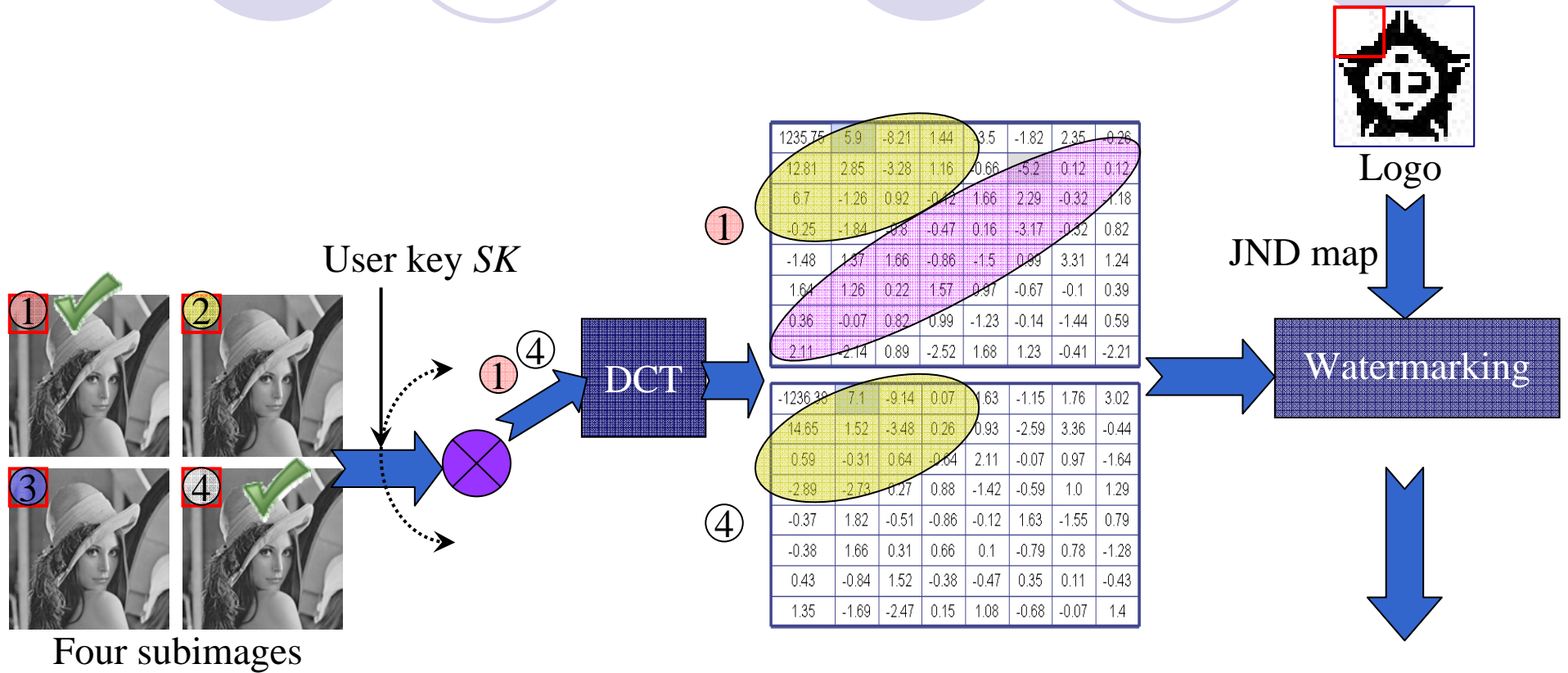
- ✓ Preserve the quality of the watermarked image
- ✓ Resist the malicious attacks
- ✓ Protect the content of artistic images, and valuable images
- ✓ Achieve the removability



Architecture



The Proposed Scheme



| | | | | | | | |
|----------|-------|-------|-------|-------|-------|-------|-------|
| 1235.75 | 5.9 | -8.21 | 1.44 | -3.5 | -1.82 | 2.35 | -0.26 |
| 12.81 | 2.85 | -3.28 | 1.16 | -0.66 | -5.2 | 0.12 | 0.12 |
| 6.7 | -1.26 | 0.92 | -0.12 | 1.66 | 2.29 | -0.32 | -1.18 |
| -0.25 | -1.84 | -0.8 | -0.47 | 0.16 | -3.17 | -0.32 | 0.82 |
| -1.48 | 1.37 | 1.66 | -0.86 | -1.5 | 0.99 | 3.31 | 1.24 |
| 1.64 | 1.26 | 0.22 | 1.57 | 0.97 | -0.67 | -0.1 | 0.39 |
| 0.36 | -0.07 | 0.82 | 0.99 | -1.23 | -0.14 | -1.44 | 0.59 |
| 2.11 | -2.14 | 0.89 | -2.52 | 1.68 | 1.23 | -0.41 | -2.21 |
| -1236.38 | 7.1 | -9.14 | 0.07 | 1.63 | -1.15 | 1.76 | 3.02 |
| 14.65 | 1.52 | -3.48 | 0.26 | 0.93 | -2.59 | 3.36 | -0.44 |
| 0.59 | -0.31 | 0.64 | -0.64 | 2.11 | -0.07 | 0.97 | -1.64 |
| -2.89 | -2.73 | 0.27 | 0.88 | -1.42 | -0.59 | 1.0 | 1.29 |
| -0.37 | 1.82 | -0.51 | -0.86 | -0.12 | 1.63 | -1.55 | 0.79 |
| -0.38 | 1.66 | 0.31 | 0.66 | 0.1 | -0.79 | 0.78 | -1.28 |
| 0.43 | -0.84 | 1.52 | -0.38 | -0.47 | 0.35 | 0.11 | -0.43 |
| 1.35 | -1.69 | -2.47 | 0.15 | 1.08 | -0.68 | -0.07 | 1.4 |

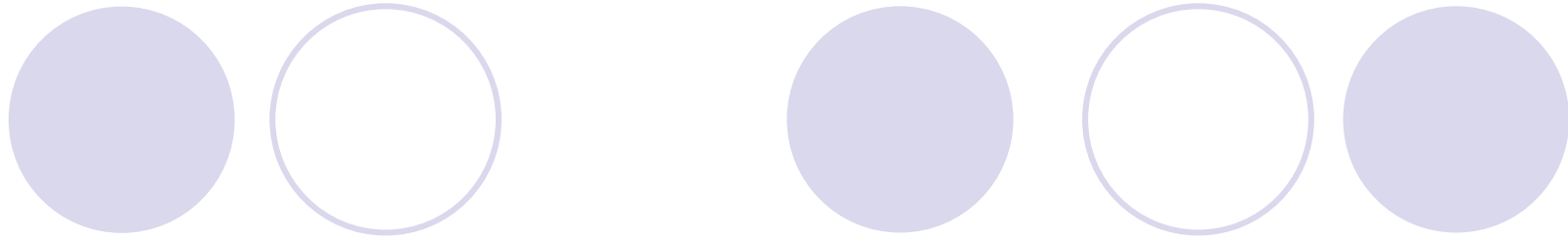
| | | | | | | | |
|---------|-------|-------|-------|-------|-------|-------|-------|
| 1235.75 | 9.2 | -8.21 | 1.44 | -3.5 | -1.82 | 2.35 | -0.26 |
| 12.81 | 2.85 | -3.28 | 1.16 | -0.66 | -13.2 | 0.12 | 0.12 |
| 6.7 | -1.26 | 0.92 | -0.12 | 1.66 | 2.29 | -0.32 | -1.18 |
| -0.25 | -1.84 | -0.8 | -0.47 | 0.16 | -3.17 | -0.32 | 0.82 |
| -1.48 | 1.37 | 1.66 | -0.86 | -1.5 | 0.99 | 3.31 | 1.24 |
| 1.64 | 1.26 | 0.22 | 1.57 | 0.97 | -0.67 | -0.1 | 0.39 |
| 0.36 | -0.07 | 0.82 | 0.99 | -1.23 | -0.14 | -1.44 | 0.59 |
| 2.11 | -2.14 | 0.89 | -2.52 | 1.68 | 1.23 | -0.41 | -2.21 |

| | | | | | | | |
|----------|-------|-------|-------|-------|-------|-------|-------|
| -1236.38 | 3.8 | -9.14 | 0.07 | 1.63 | -1.15 | 1.76 | 3.02 |
| 14.65 | 1.52 | -3.48 | 0.26 | 0.93 | -2.59 | 3.36 | -0.44 |
| 0.59 | -0.31 | 0.64 | -0.64 | 2.11 | -0.07 | 0.97 | -1.64 |
| -2.89 | -2.73 | 0.27 | 0.88 | -1.42 | -0.59 | 1.0 | 1.29 |
| -0.37 | 1.82 | -0.51 | -0.86 | -0.12 | 1.63 | -1.55 | 0.79 |
| -0.38 | 1.66 | 0.31 | 0.66 | 0.1 | -0.79 | 0.78 | -1.28 |
| 0.43 | -0.84 | 1.52 | -0.38 | -0.47 | 0.35 | 0.11 | -0.43 |
| 1.35 | -1.69 | -2.47 | 0.15 | 1.08 | -0.68 | -0.07 | 1.4 |

Experimental Results

The image quality of watermarked and restored images, and *AR*'s of extracted watermarks under different *r*'s.

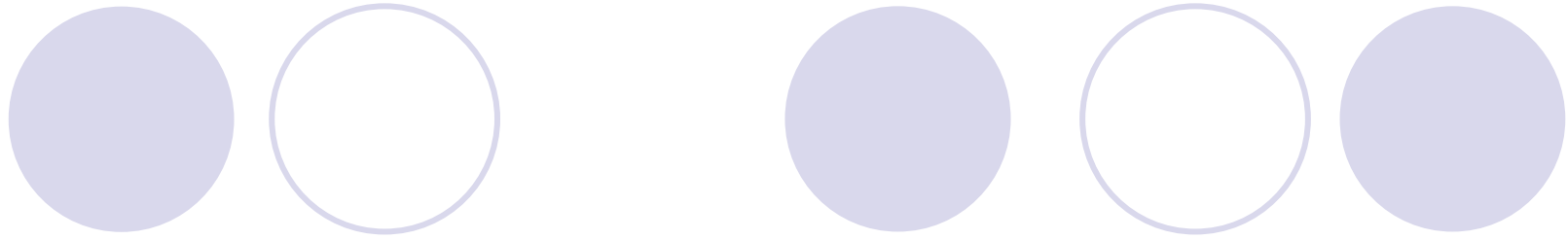
| Original image | <i>r</i> | Image quality | | | | | | <i>AR</i> |
|----------------|----------|---------------|------------|--------|-----------|------------|--------|-----------|
| | | Watermarked | | | Restored | | | |
| | | PSNR (dB) | wPSNR (dB) | SSIM | PSNR (dB) | wPSNR (dB) | SSIM | |
| Airplane | 3 | 40.24 | 60.74 | 0.9899 | 56.60 | 76.65 | 0.9997 | 1.00 |
| | 5 | 37.40 | 58.99 | 0.9795 | 52.37 | 73.93 | 0.9994 | 1.00 |
| Baboon | 3 | 35.06 | 46.97 | 0.9843 | 49.68 | 61.87 | 0.9992 | 1.00 |
| | 5 | 33.45 | 46.07 | 0.9781 | 49.12 | 63.39 | 0.9991 | 1.00 |
| Girl | 3 | 40.87 | 52.81 | 0.9766 | 56.36 | 71.66 | 0.9995 | 1.00 |
| | 5 | 38.35 | 51.54 | 0.9658 | 52.75 | 64.65 | 0.9979 | 1.00 |
| Goldhill | 3 | 41.23 | 56.50 | 0.9849 | 56.10 | 71.96 | 0.9995 | 1.00 |
| | 5 | 39.14 | 55.89 | 0.9806 | 53.97 | 71.38 | 0.9995 | 1.00 |
| Lena | 3 | 42.66 | 59.53 | 0.9964 | 59.88 | 75.33 | 0.9999 | 1.00 |
| | 5 | 39.40 | 57.76 | 0.9936 | 56.07 | 72.59 | 0.9998 | 1.00 |
| Peppers | 3 | 41.99 | 57.65 | 0.9968 | 55.37 | 74.54 | 0.9999 | 1.00 |
| | 5 | 39.75 | 55.94 | 0.9944 | 52.31 | 71.06 | 0.9997 | 1.00 |
| Sailboat | 3 | 39.07 | 52.03 | 0.9931 | 54.59 | 69.71 | 0.9999 | 1.00 |
| | 5 | 36.66 | 50.75 | 0.9897 | 51.57 | 67.86 | 0.9998 | 1.00 |
| Tiffany | 3 | 41.81 | 59.88 | 0.9915 | 50.38 | 73.73 | 0.9996 | 1.00 |
| | 5 | 39.81 | 58.12 | 0.9859 | 50.69 | 73.92 | 0.9997 | 1.00 |
| Average | 3 | 40.37 | 55.76 | 0.9892 | 54.87 | 71.93 | 0.9997 | 1.00 |
| | 5 | 38.00 | 54.38 | 0.9835 | 52.36 | 69.85 | 0.9994 | 1.00 |



The comparison of the restored PSNR values between [10] and ours.

| Original image | Restored PSNR (dB) | | |
|----------------|--------------------|-----|-------|
| | Hu et al. [10] | r | Ours |
| Airplane | 44.16 | 3 | 56.60 |
| | | 5 | 52.37 |
| Girl | 43.54 | 3 | 56.36 |
| | | 5 | 52.75 |
| Lena | 44.15 | 3 | 59.88 |
| | | 5 | 56.07 |
| Peppers | 44.11 | 3 | 55.37 |
| | | 5 | 52.31 |
| Sailboat | 44.15 | 3 | 54.59 |
| | | 5 | 51.57 |

[10] Y. Hu, S. Kwong, J. Huang, An algorithm for removable visible watermarking, *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 16, no. 1, pp. 129–133, 2006.



(a) The original image



(b) The watermarked image



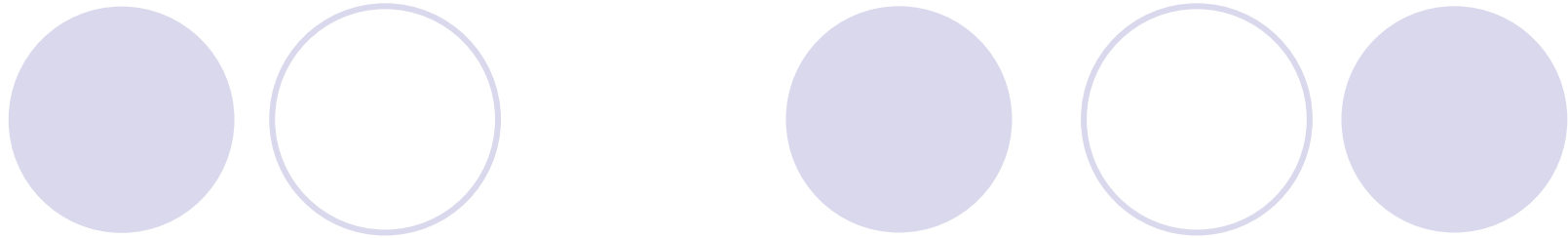
(c) The restored image,
PSNR=59.88 dB



The comparison between [13] and ours under various signal processing attacks $r = 5$.

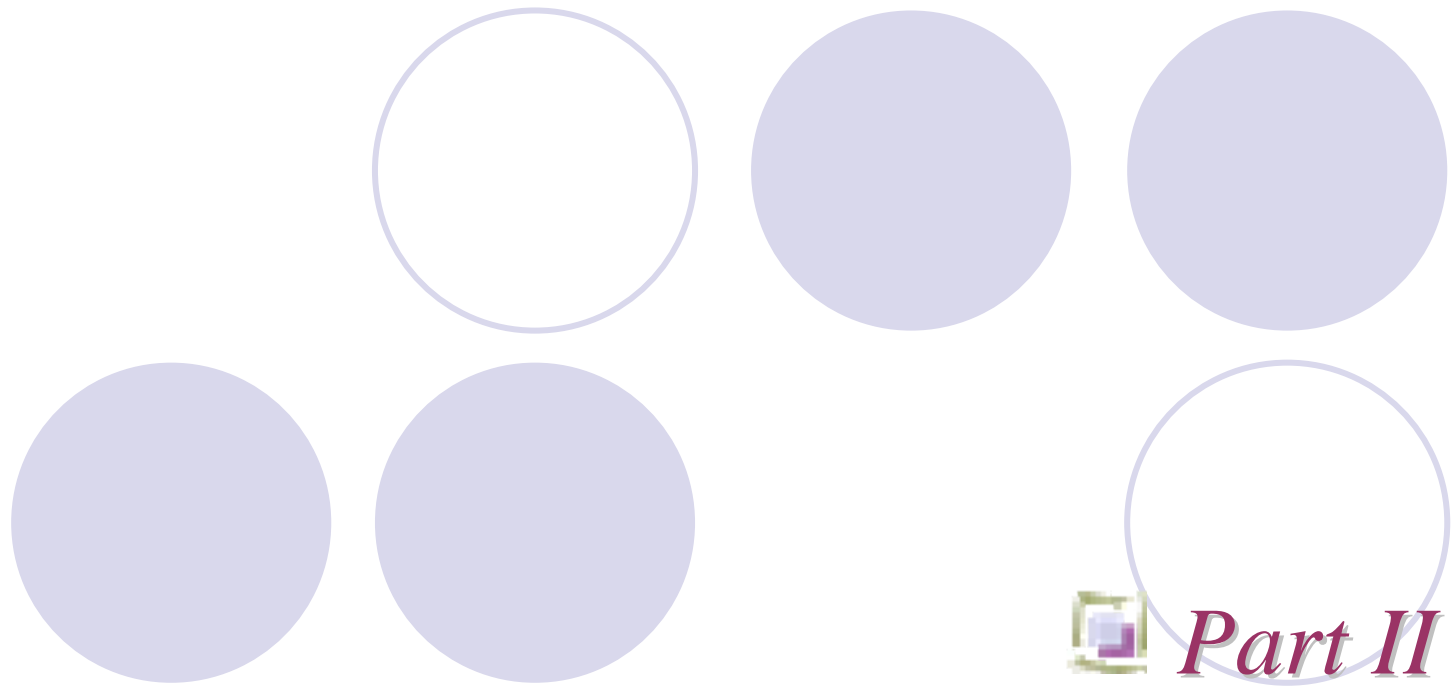
| Attack | Lu et al. [13] | | Ours | |
|---------------------------------|----------------|-------|-------|-------|
| | PSNR | AR | PSNR | AR |
| Blurring (Gaussian 0.5) | 38.98 | 59.47 | 38.83 | 90.34 |
| Brightness (50) | 14.17 | 90.53 | 14.17 | 99.71 |
| Brightness (50) + Contrast (50) | 9.83 | 80.95 | 9.83 | 87.70 |
| Contrast (50) | 16.72 | 83.69 | 16.69 | 95.61 |
| Cropping (rate 10%) | 15.29 | 82.42 | 15.29 | 95.02 |
| Cropping (rate 20%) | 12.39 | 78.22 | 12.38 | 87.50 |
| Cropping (rate 30%) | 10.58 | 75.10 | 10.58 | 81.84 |
| Cropping (rate 40%) | 9.41 | 70.02 | 9.41 | 76.86 |
| Cropping (rate 50%) | 8.34 | 64.65 | 8.33 | 72.56 |
| Cropping (rate 60%) | 7.36 | 59.77 | 7.35 | 66.31 |
| Cropping (around) | 9.04 | 57.81 | 9.03 | 72.56 |
| Equalization | 19.15 | 90.13 | 19.11 | 100 |
| Gaussian Noising (3%) | 30.13 | 80.96 | 29.84 | 97.95 |
| Gaussian Noising (6%) | 24.48 | 73.73 | 24.54 | 87.21 |
| Gaussian Noising (9%) | 20.81 | 68.46 | 20.84 | 80.77 |
| JPEG (Q = 6) | 39.62 | 67.38 | 38.59 | 92.29 |
| JPEG (Q = 8) | 40.04 | 72.26 | 38.62 | 97.27 |
| JPEG (Q = 10) | 41.66 | 86.62 | 38.94 | 100 |
| PSNR100 | 20.15 | 90.63 | 20.12 | 100 |
| Rotation (degree 2) | 13.99 | 49.21 | 13.98 | 51.47 |
| Scaling (75%) | 25.28 | 66.21 | 25.21 | 95.90 |
| Scaling (200%) | 25.64 | 89.36 | 25.56 | 100 |
| Sharpening | 33.55 | 91.40 | 26.19 | 100 |





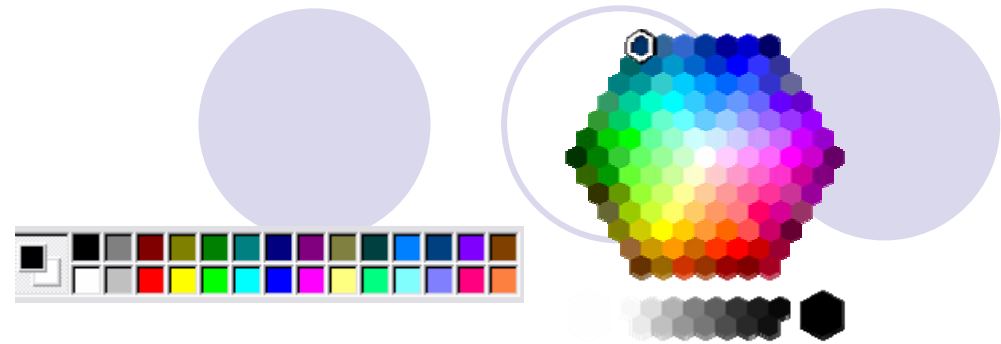
The functionality comparison between traditional watermarking schemes and the novel scheme.

| | [1,4-6,9,17] | Hu et al. [10] | The novel scheme |
|-------------------------------|--------------|-----------------|--|
| Restorability | Reversible | Removable | Removable |
| Transparency | Lossless | Some distortion | Approximately-lossless |
| Security | Yes | Yes | Yes |
| Unambiguity | Yes | Yes | Yes |
| Blindness | Yes | Yes | Yes |
| Suitability for Medical Image | Yes | Yes | Yes |
| Visual recognizable logo | Yes | Yes | Yes |
| Robustness | None | None | Blurring Brightness Contrast Cropping Equalization JPEG Noising Scaling Sharpening |

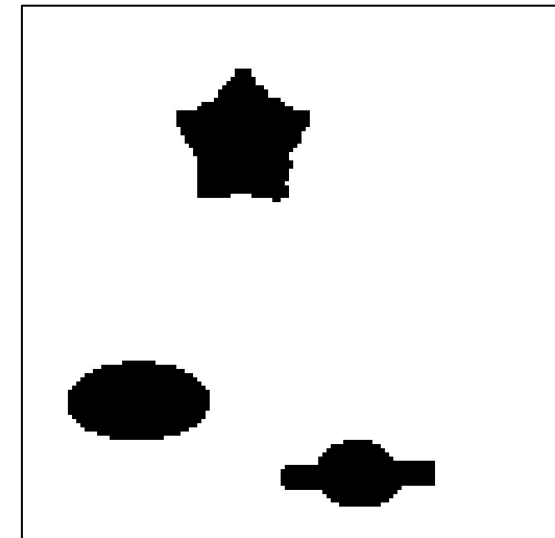
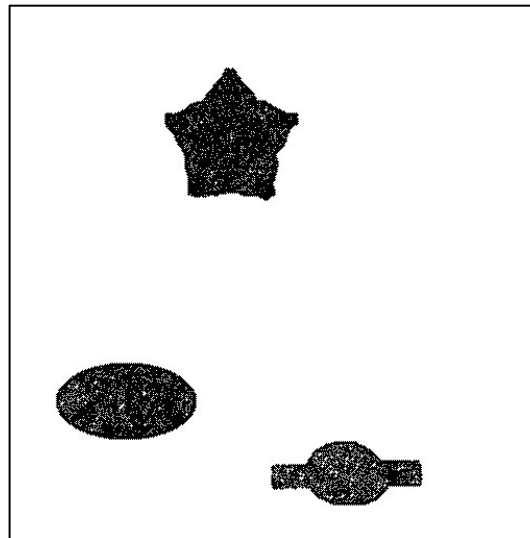


Authentication Scheme for Palette-based Color Images

Motivation



- Palette-based color image compression, such as GIF images.
- Pixel-based detection & block-based detection
- Partitioned Palette & Morphological operations

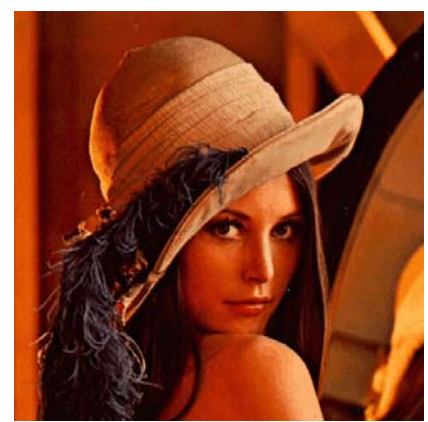


The Proposed Scheme

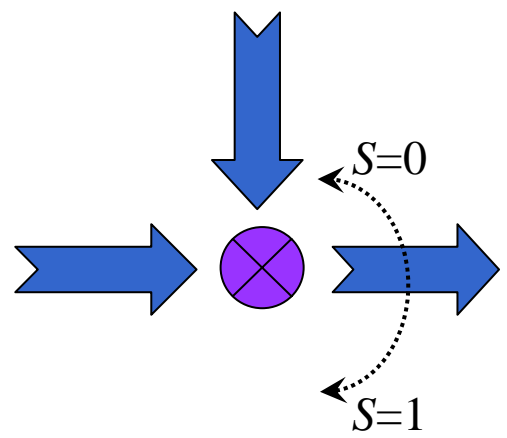


User key SK
Authentication code

G_0 G_1

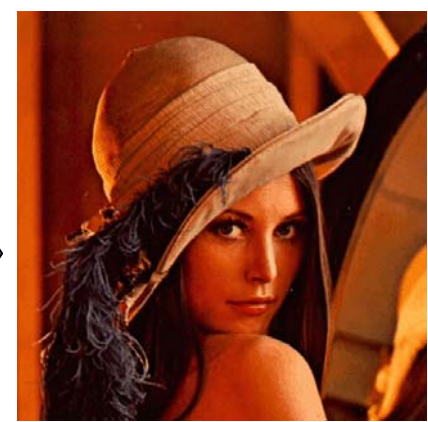


Protected image



Palette

| | |
|-------------------|-------|
| (r_0, g_0, b_0) | G_0 |
| (r_1, g_1, b_1) | G_1 |
| (r_2, g_2, b_2) | G_1 |
| (r_2, g_2, b_2) | G_0 |
| (r_4, g_4, b_4) | G_0 |
| (r_5, g_5, b_5) | G_1 |
| (r_6, g_6, b_6) | G_1 |
| (r_7, g_7, b_7) | G_0 |
| (r_8, g_8, b_8) | G_1 |
| (r_9, g_9, b_9) | G_0 |



Authenticated indexed image₂₁

The Extracting Procedure



G_0 G_1

Palette

| | |
|-------------------|-------|
| (r_0, g_0, b_0) | C_0 |
| (r_1, g_1, b_1) | G_1 |
| (r_2, g_2, b_2) | G_1 |
| (r_3, g_3, b_3) | C_0 |
| (r_4, g_4, b_4) | C_0 |
| (r_5, g_5, b_5) | G_1 |
| (r_6, g_6, b_6) | G_1 |
| (r_7, g_7, b_7) | C_0 |
| (r_8, g_8, b_8) | G_1 |
| (r_9, g_9, b_9) | C_0 |

$S=0$

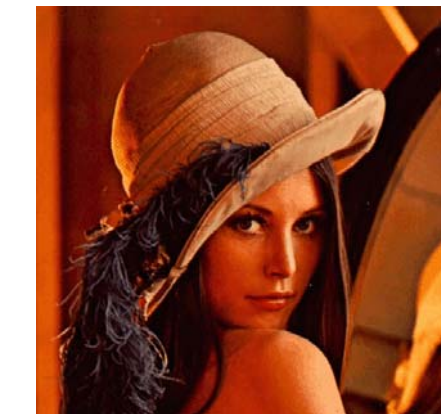
$S=1$

Extracting

User key SK
Authentication code

Comparing

Extracted code

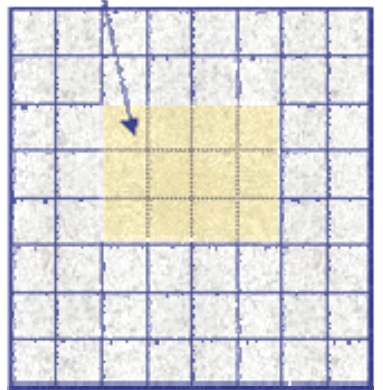


Authenticated indexed image



User key SK
 Authentication code

Modified Area



Modified image

Random(secret key)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |

Extraction data

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |

Extracted code

Exclusive-Or \oplus

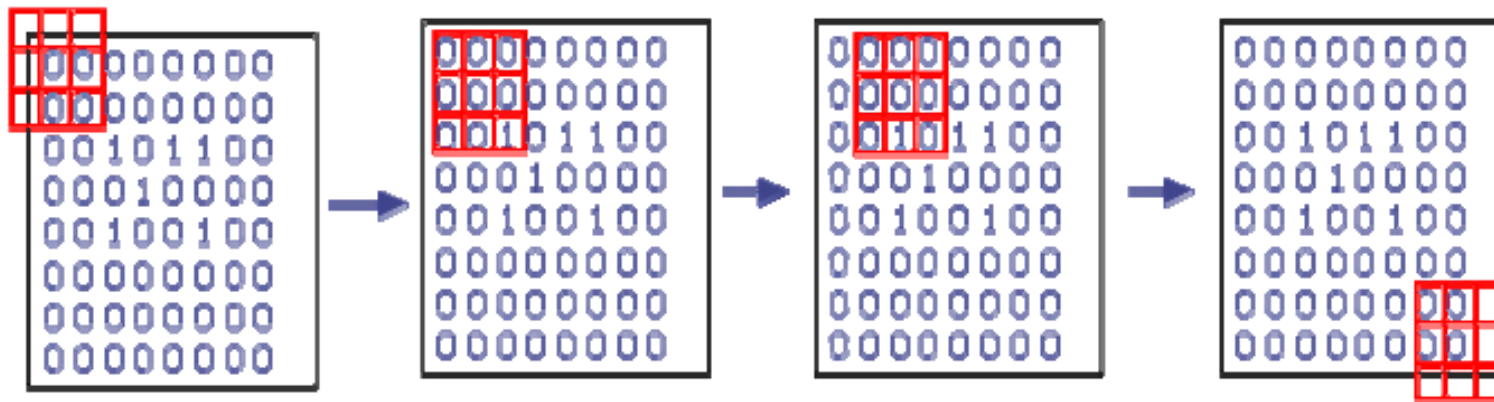
Difference Location Panel

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

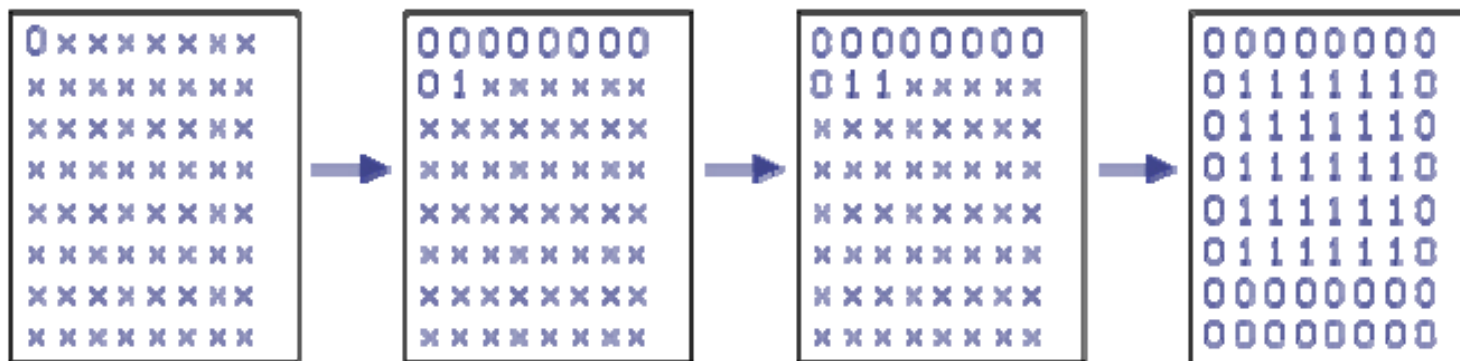
The Morphological Operations

Dilation operator

Difference Location Panel

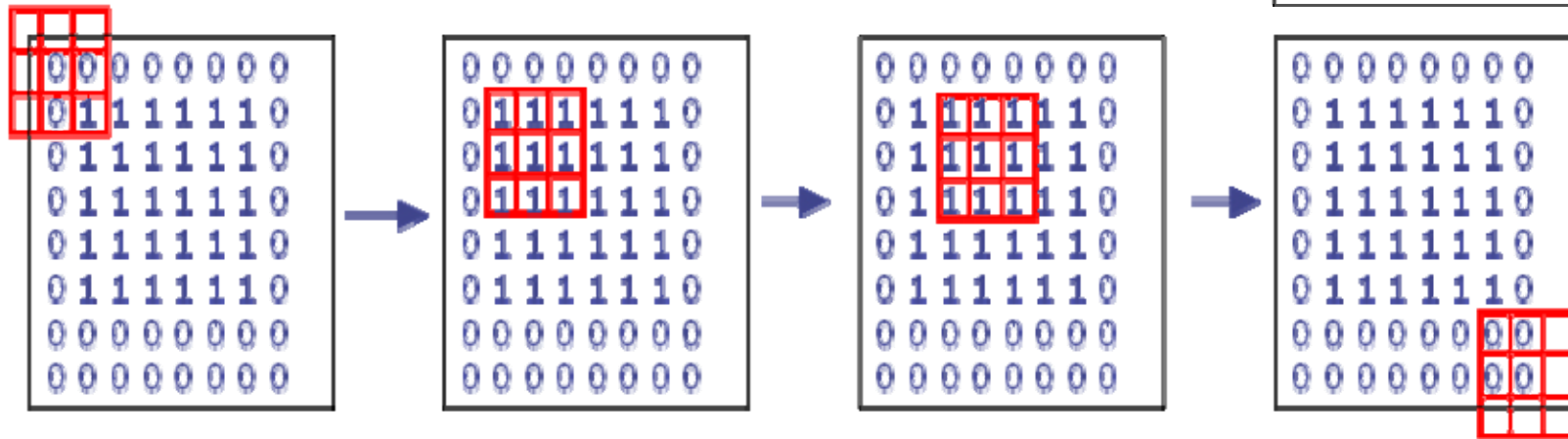


Difference Location Panel with dilation

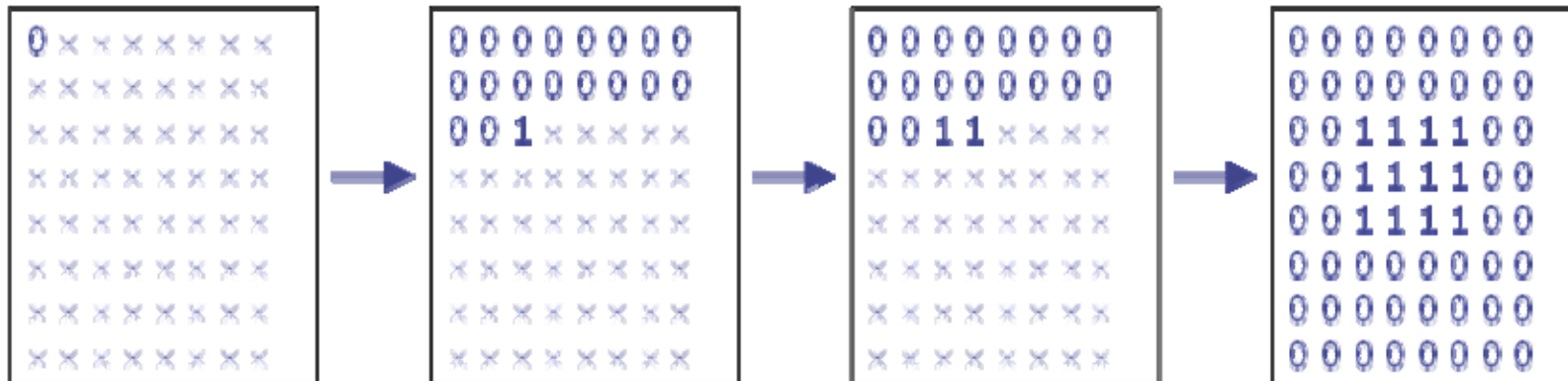


Erosion operator

Difference Location Panel with dilation



Difference Location Panel with erosion



Experimental Results



PSNR=41.89 dB



Tampered image



Detection



Detection
(Morphological)



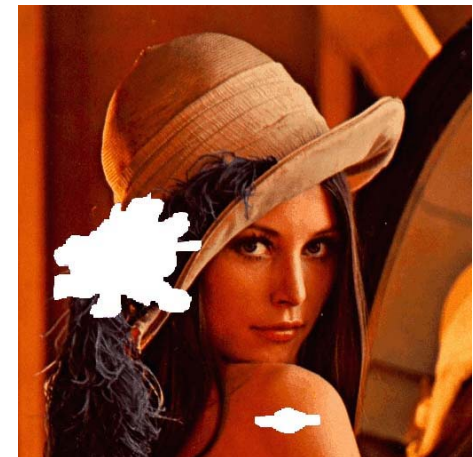
PSNR=39.99 dB



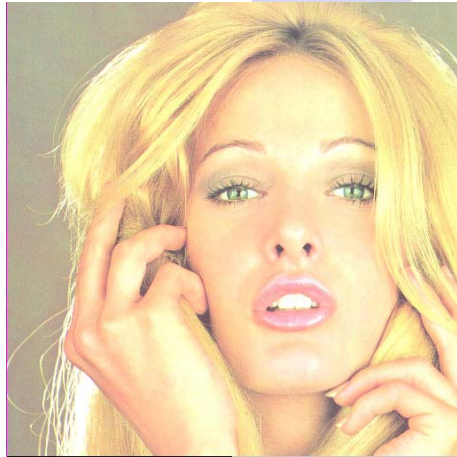
Tampered image



Detection



Detection₂₅
(Morphological)



PSNR=36.73 dB



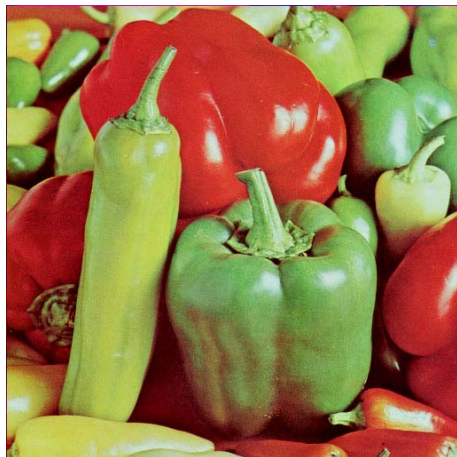
Tampered image



Detection



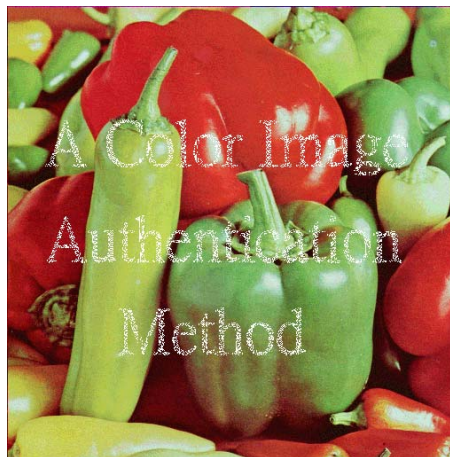
Detection
(Morphological)



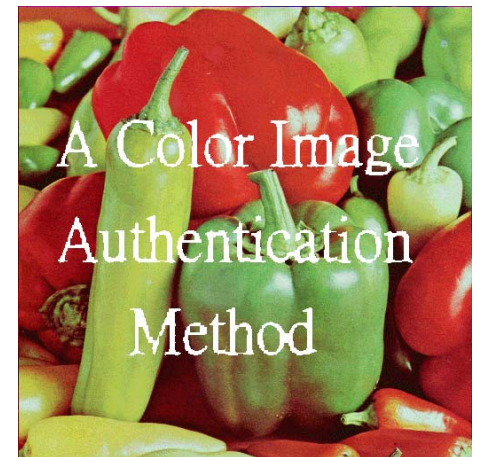
PSNR=38.2 dB



Tampered image



Detection



Detection₂₇
(Morphological)

Conclusions and Future Works

Part I: Robust watermarking

- Robust and removable digital watermarking
- Ⓢ Enhance restored image quality
- Ⓢ Design a dual watermarking system
 - Ⓢ Visual logo can be used to exhibit the visual logo from multimedia
 - Ⓢ Invisible logo can be used to protect the copyright without revealing the logo and enhance the robustness

Part II: Image Authentication

- Authentication for palette-based color images and grayscale images
 - Ⓢ Repair the tampered area
 - Ⓢ Removable image authentication
- Ⓢ Apply to digital library, digital archive, digital museum, and electronic commercial

The text is centered and surrounded by six light purple circles. Three circles are arranged in a top row, and three are in a bottom row. The top-left circle is an outline, while the top-middle and top-right circles are solid. The bottom-left and bottom-middle circles are solid, while the bottom-right circle is an outline.

Thanks for your listening~