Automatic Contrast Enhancement using Reversible Data Hiding

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Introduction

Automatic image enhancement

- When user uploads an image
  - Automatically enhance the image (without user's inputs)
  - With original image recoverability (user is not satisfied with the enhancement)
- "Make them look better without any efforts on user's behalf"
- Two existing solutions
  - Keep the original image
  - Non destructive editing (keep track of the enhancement in an XML format)

Apple

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Drawbacks

- Keep the original image
  - **Increase** in **storage requirement** - keeping the original image
- XML based
  - Enhanced image **cannot** be decoded by the standard image decoder
  - Enhancements are not standardized (highly depended on the software and the company)

Goals

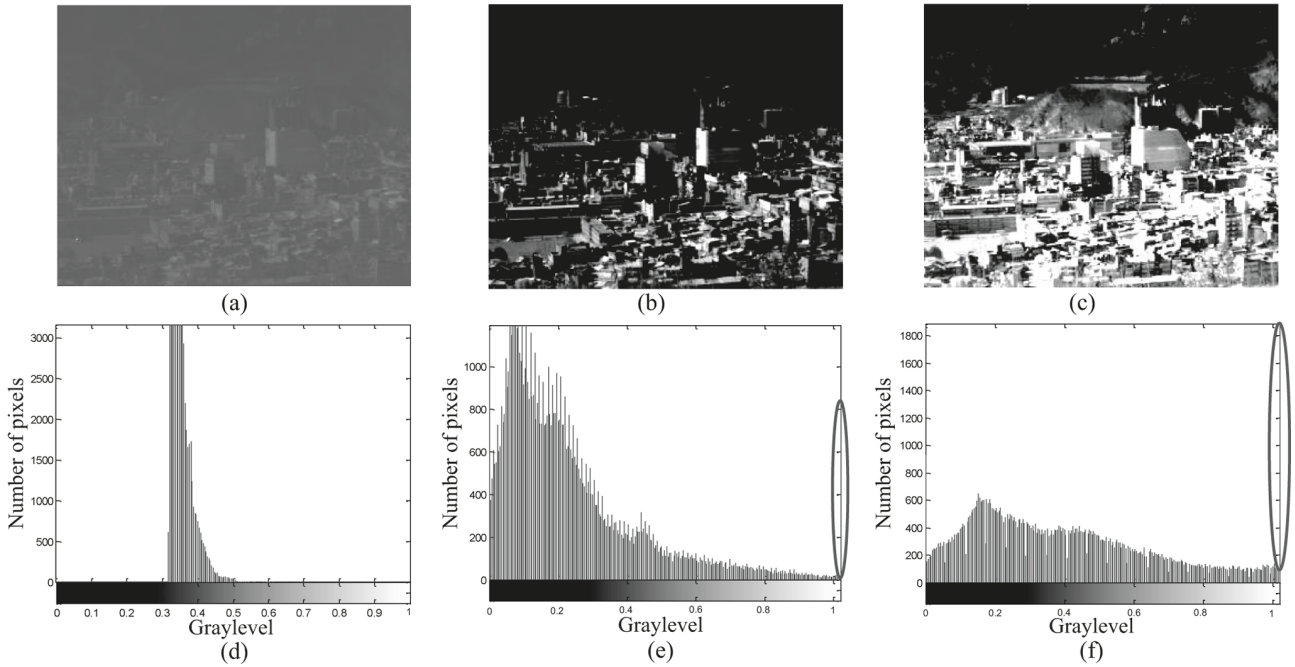
- Find a solution which provides
  - Good contrast enhancement
  - Reduced storage requirements
  - Decodability of the enhanced using the standard decoder (original image recoverability with a special decoder)
  - Data hiding for integrity checking (Embed integrity checking value)

Proposed Method

Contrast enhancement

Contrast enhancement

- Useful for enhancing under and over exposed images
- Achieved using histogram equalization



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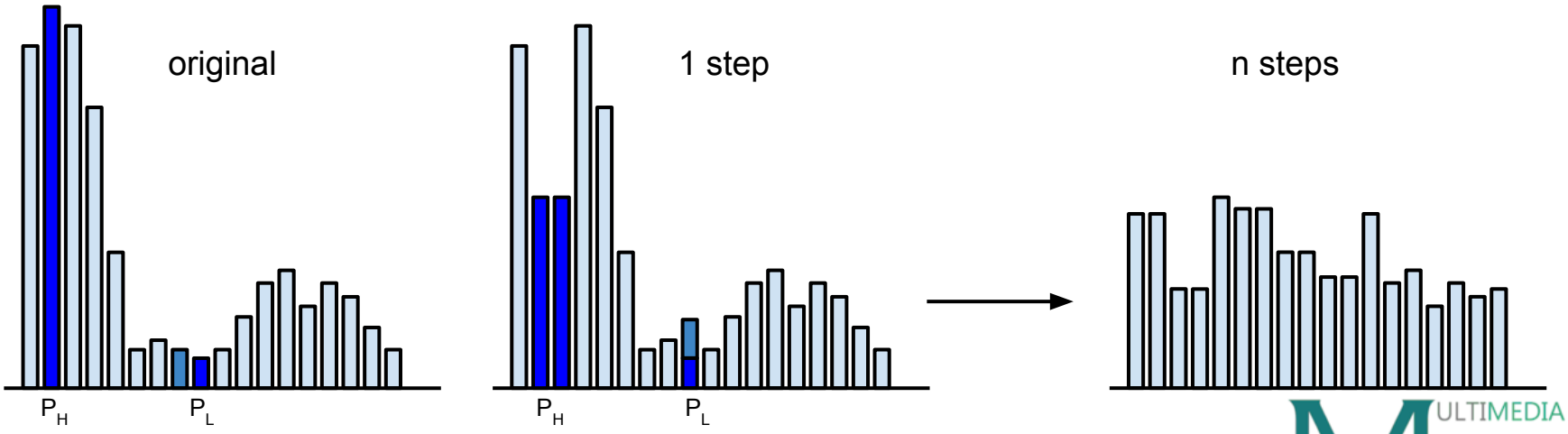
Overview

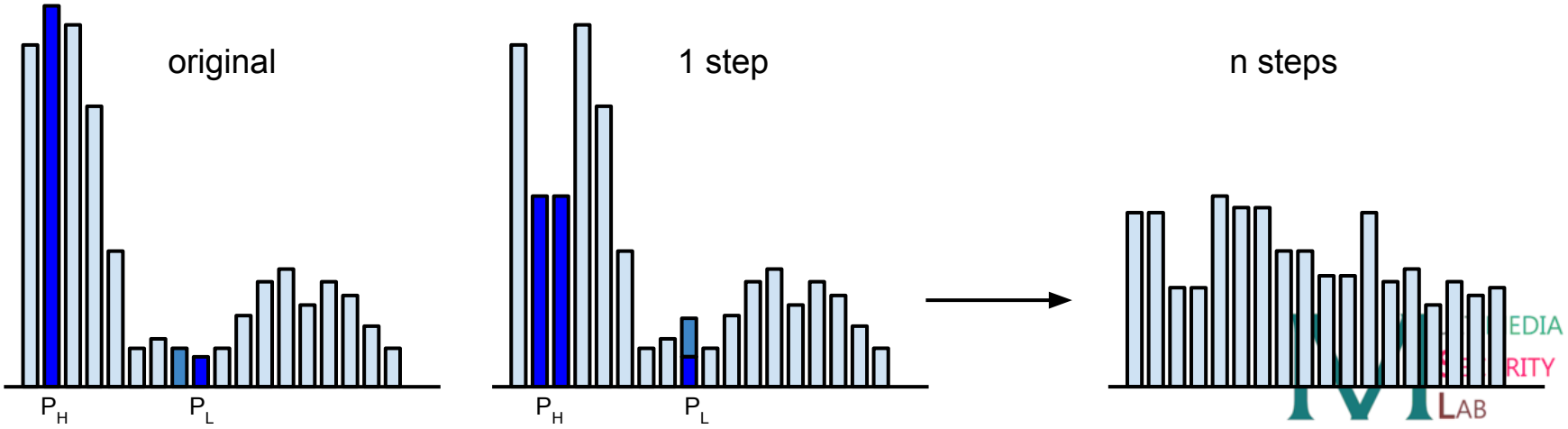
- Histogram Equalization can be achieved using histogram shifting
  - Split the most frequent bin into two bins (iteratively)
- Histogram shifting is a reversible operation (when used with location map)



Unidirectional histogram shifting

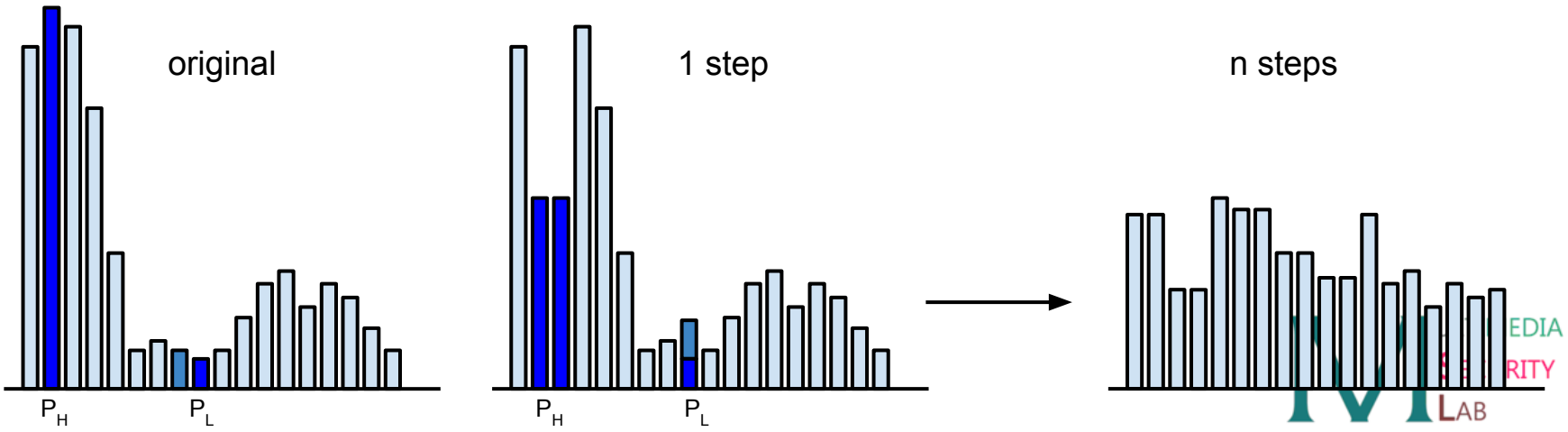
For every iteration of histogram shifting

- Find the most frequent bin P_H
- Find the least frequent bin P_L which is located on the right of P_H
- If $P_H <= P_L$
  - Positive histogram shifting (PHS)
- If $P_H > P_L$
  - Negative histogram shifting (NHS)



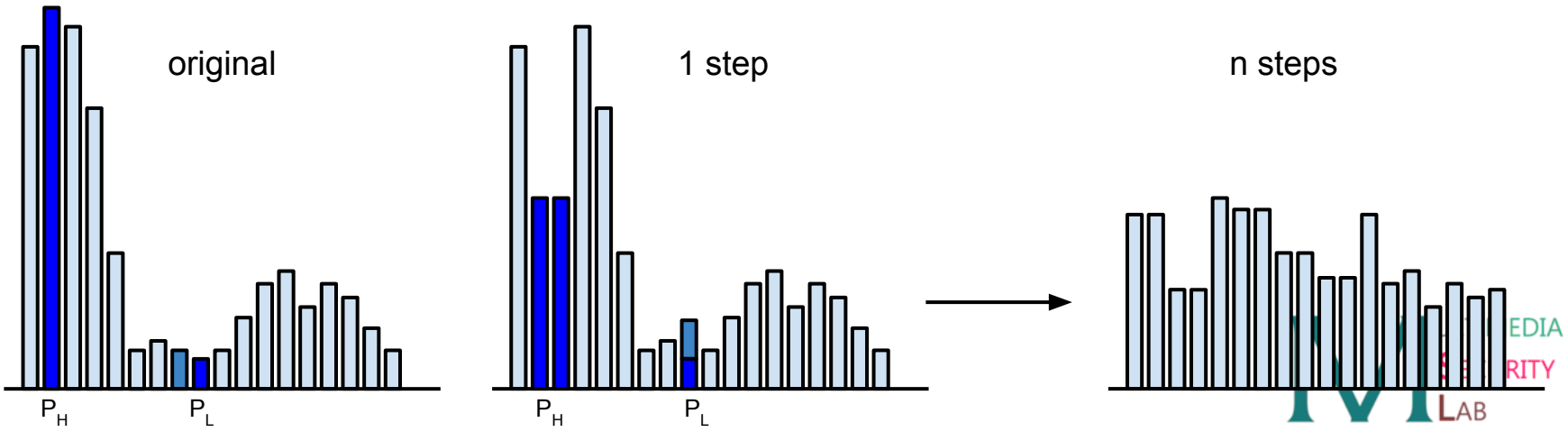
Positive histogram shifting (PHS)

- Combine bin P_L-1 and P_L
- Create an empty bin (all pixels between P_H and P_L is shifted by 1)
- Embed data in bins P_H and P_H+1



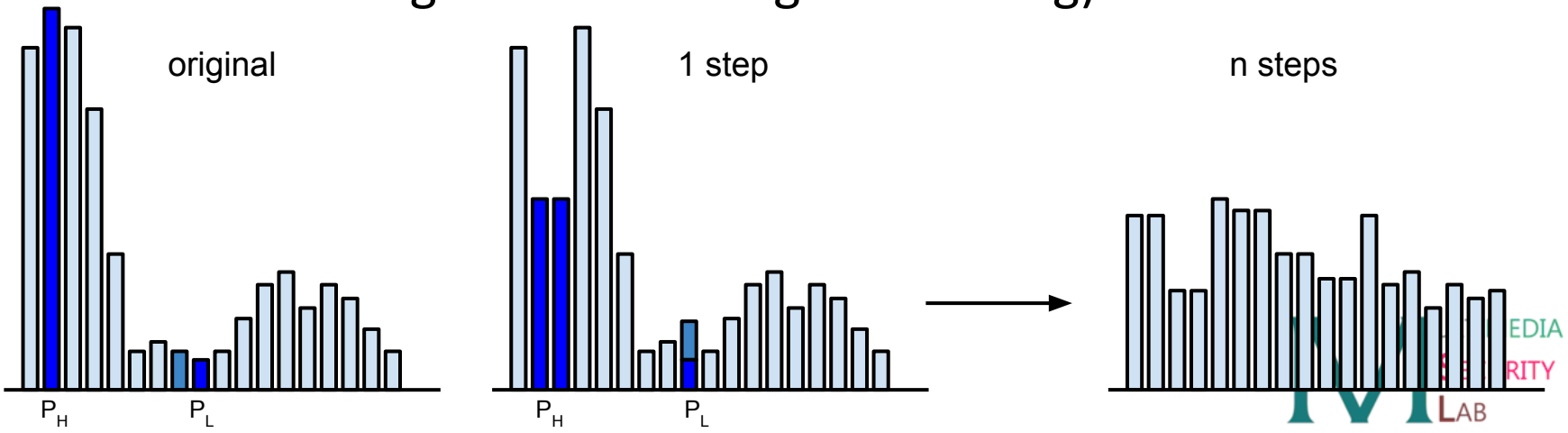
Embedding

- Number of pixels equal to P_H = embedding capacity
- For every pixel values P_H
  - If embedding bit is
    - 0, leave it as P_H
    - 1, modify P_H to P_H+1
- Extraction is trivial
- Negative histogram shifting can be applied in similar fashion (rest of the presentation will explain using PHS)



Reversibility

- What happens when the most frequent bin is split?
  - Pixels are shifted towards the bin P_L
  - Bins P_L and P_L-1 are combined (PHS)
  - Bins P_L and P_L-1 are combined (NHS)
- How to make it reversible?
  - Create a location map
  - Embed side information for reversibility (current P_L and P_L values during the next histogram shifting)



Concurrent location map

- Location map
  - create a separate binary string indicating which P_L pixels are originally P_L-1
- For each combined P_L pixels,
  - If originally P_L then mark 0
  - If originally P_L then mark 1
- Size of location map is equal to the number of P_L and P_L-1 pixels
- (Optionally) compress using arithmetic coding

Stop condition

- Higher number of iterations leads to more equalized histogram => maximize number of iterations
- Stop condition:
  - Location map size > embedding capacity

Side information

- Current P_H and P_L
  - Embedded in the next histogram shifting round
    - In case of the last round, they are recorded using LSB replacement (original pixel values are embedded in the current histogram shifting round)
- Location map
  - Embedded in the current histogram shifting round
- Last flag
  - Indicates whether the current histogram shifting round is the first round
  - Embedded in the current histogram shifting round
- Compression flag

Recoverability of the original image

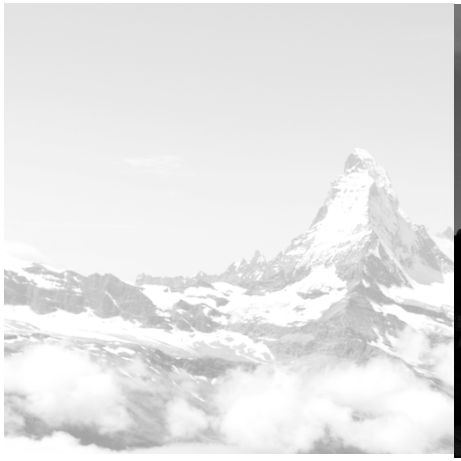
- Read the first 8 LSBs of the image to find P_H and P_L
- Undo histogram shifting
- Repeat histogram shifting until the “last flag” is found

Experimental Results

Test Images

- 4 test images (over and under) and 4 SIPI
- 512 x 512 color images converted into grey scaled image

Visual Evaluation



a) Matterhorn

b) Hanok

c) Creek

d) Plane

- 4 low contrast images are tested
- 2 under-exposed (dark) and 2 over-exposed (light)

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Matterhorn

original

16 iterations

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Matterhorn

original

32 iterations

Matterhorn

original

48 iterations

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Matterhorn

original

64 iterations

Matterhorn

original

80 iterations

Matterhorn

original

96 iterations

Matterhorn

original

112 iterations

Matterhorn

original

120 iterations
(Max)

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Plane

a) Original

b) Proposed

c) Histeq

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Hanok

a) Original

b) Proposed

c) Histeq

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Creek

a) Original

b) Proposed

c) Histeq

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Color Extension (sign)

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Embedding Capacity

- Lena
  - 130,000 bits
- Boat
  - 180,000 bits
- Barbara
  - 70,000 bits
- Airplane
  - 310,000 bits

Related work

- Wu et al.
  - Limitations:
    - Not automatic (preset number of iterations)
    - Enhancement is very bad for large number of iterations (due to bad implementation of location map)
    - Hard to predict the enhancement effect
    - Unsuitable for automatic contrast enhancement
  - More details can be found in our paper

Applications

- Automatic image enhancement
  - Enhanced image has equalized histogram
  - Original image doesn't have to kept
  - Interoperable with the existing image standard
  - Image integrity information can be embedded within the image

Further works

- Over enhancement can be a problem
- Extending the work to JPEG file format
- Extending the work for other image enhancement techniques

Questions?