Histogram Warping and its Applications

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Histogram Warping Framework

Publications

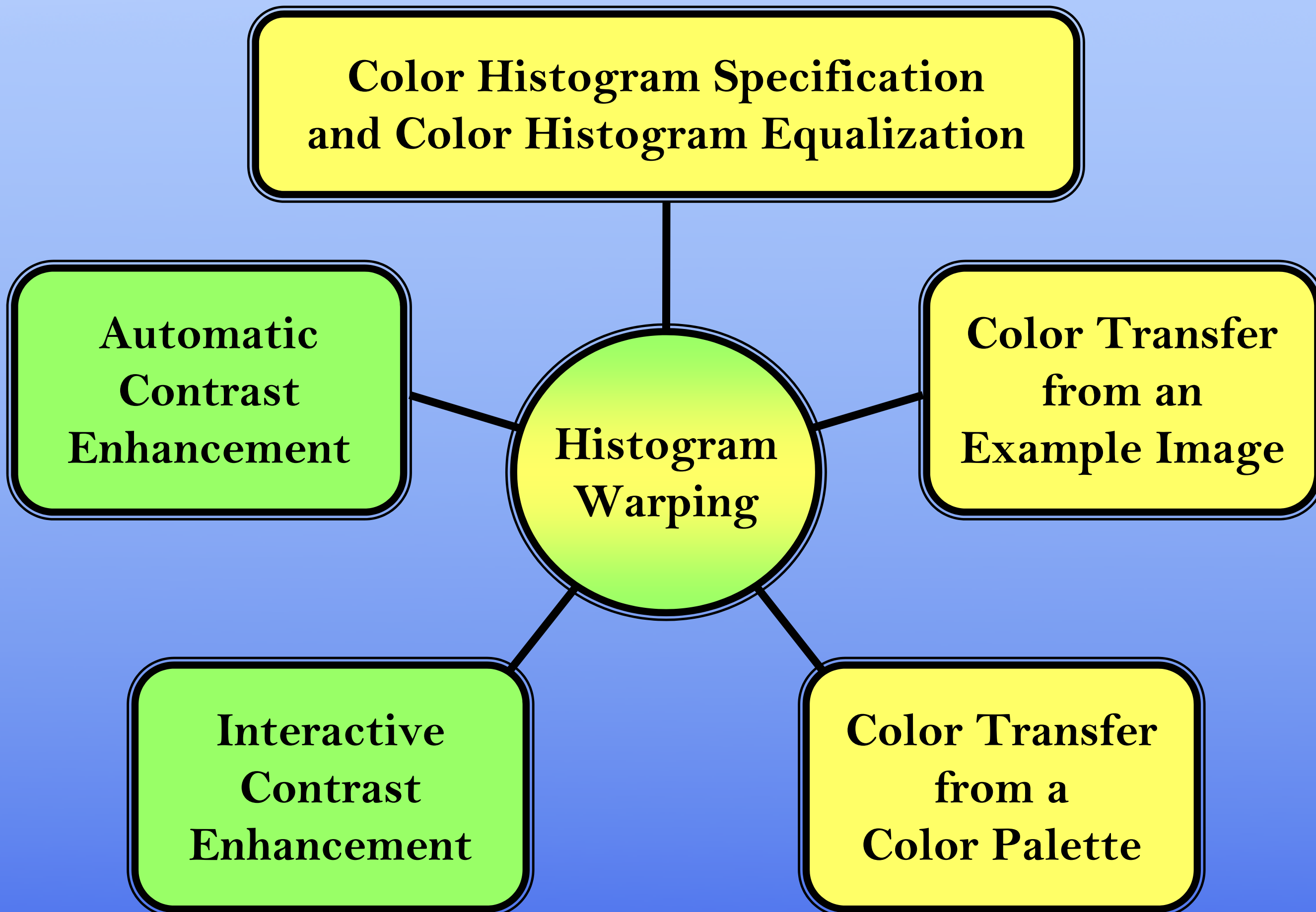
- **Interactive Contrast Enhancement by Histogram Warping**
  by Mark Grundland and Neil A. Dodgson (2004)
  International Conference on Computer Vision and Graphics

- **Automatic Contrast Enhancement by Histogram Warping**
  by Mark Grundland and Neil A. Dodgson (2004)
  International Conference on Computer Vision and Graphics

- **Color Histogram Specification by Histogram Warping**
  by Mark Grundland and Neil A. Dodgson (2005)
  Color Imaging X: Processing, Hard Copy, and Applications

Histogram Warping Framework

Applications

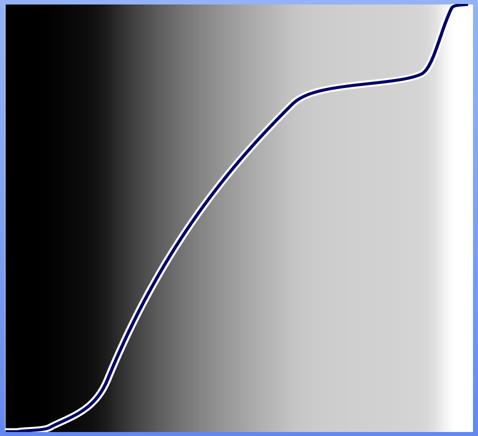


Histogram Warping Framework

Global Histogram Transformation

Formulate a global color or gray level transformation function to perform a desired image operation.

Original Image



Gray Level Transformation Function

Automatic Contrast Enhancement by Histogram Warping

Histogram Warping Framework
Requirements

- **Direct:** formulated as a mapping $y=T(x)$ of each tone of the input image to an output tone.
- **Adjustable:** separate specification of the shift in tone $T(x)$ from the change in contrast $T'(x)$.
- **Flexible:** simultaneous and independent specification of the tone and contrast adjustment at different points in the tonal range.
- **Invertible:** a monotonic, bijective function $T'(x)\geq 0$.
- **Smooth:** a continuously differentiable C^1 function.

Histogram Warping Framework
Formulation

- Map tones $b_k=T(a_k)$ using contrast adjustments $d_k=T'(a_k)$.
- Construct a continuously differentiable, monotonic function.
- Apply a piecewise rational quadratic interpolating spline:

$$T(x) = b_{k-1} + \frac{r_k t^2 + d_{k-1}(1-t)t}{r_k + (d_k + d_{k-1} - 2r_k)(1-t)t}(b_k - b_{k-1}),$$

$$\text{with } r_k = \frac{b_k - b_{k-1}}{a_k - a_{k-1}} \text{ and } t = \frac{x - a_{k-1}}{a_k - a_{k-1}} \text{ for } x \in [a_{k-1}, a_k].$$

Global Histogram Transformation

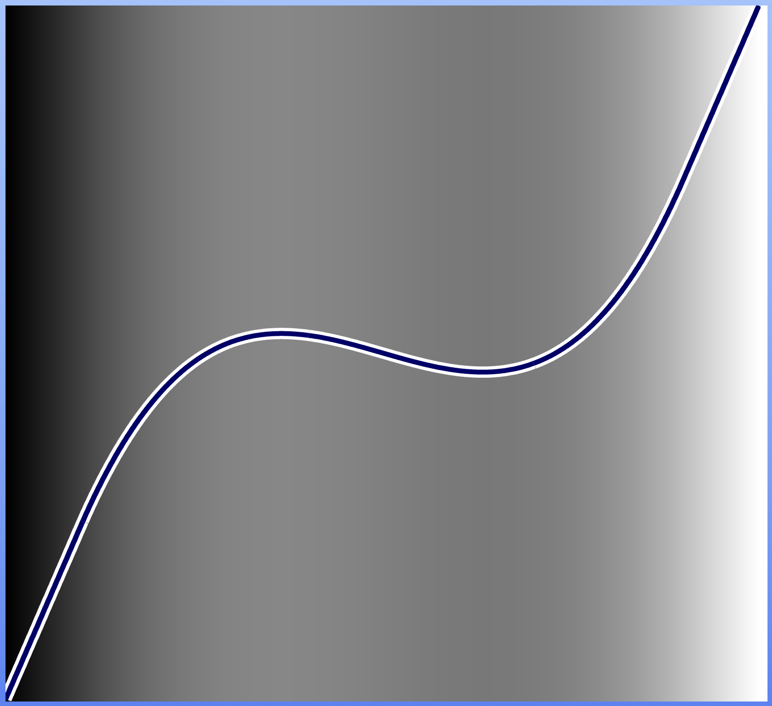
Limitations of Classical Methods

- **Histogram specification**
  Define the transformation function to produce a desired histogram.
  - Can be difficult to choose the correct histogram for a given image.
  - Can cause unintended distortion if the source histogram is not taken into account in the selection of the target histogram.
- **Parametric function**
  Apply linear, cubic, sigmoidal, logarithmic, or exponential functions.
  - Can lack the necessary degrees of freedom to express simultaneous and independent adjustments of contrast and tone at multiple points in the tonal range.
- **Piecewise defined splines**
  - Linear splines: Can fail to separately adjust tone and contrast.
  - Exponential splines: Can fail to be continuously differentiable.
  - Cubic splines: Can fail to be monotonic.

Global Histogram Transformation

Artifacts of Classical Methods

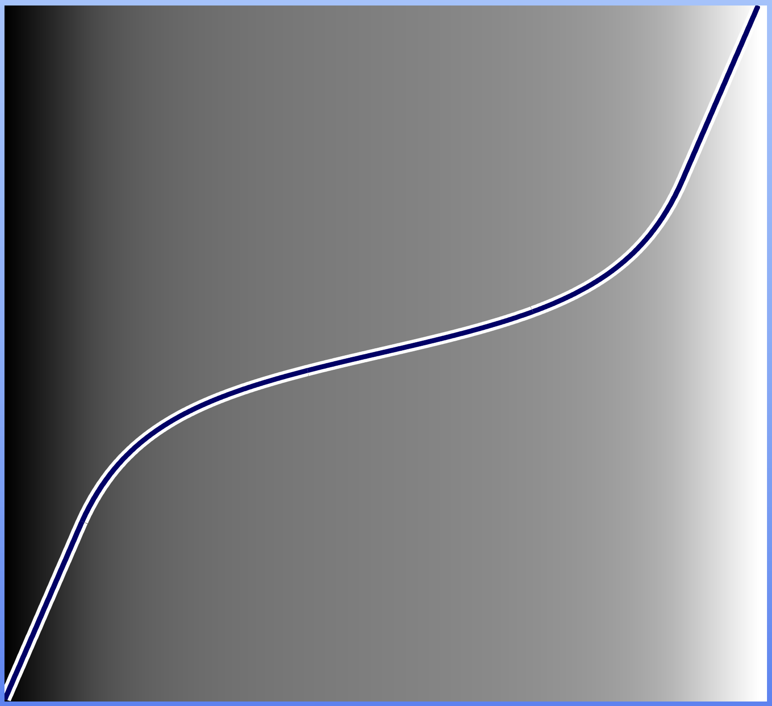
- A monotonic transformation avoids banding artifacts by preserving the natural order of tones.



C^1 Cubic Spline

T(0)=0, T(10)=25, T(90)=75, T(100)=100

T´(0)= T´(10)=T´(90)= T´(100)=2.5



C^1 Rational Quadratic Spline

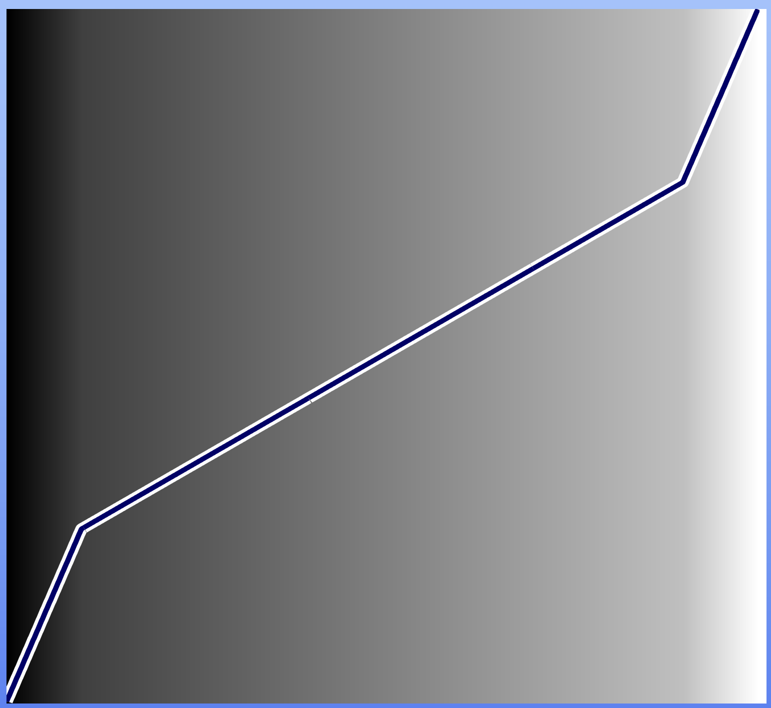
T(0)=0, T(10)=25, T(90)=75, T(100)=100

T´(0)= T´(10)=T´(90)= T´(100)=2.5

Global Histogram Transformation

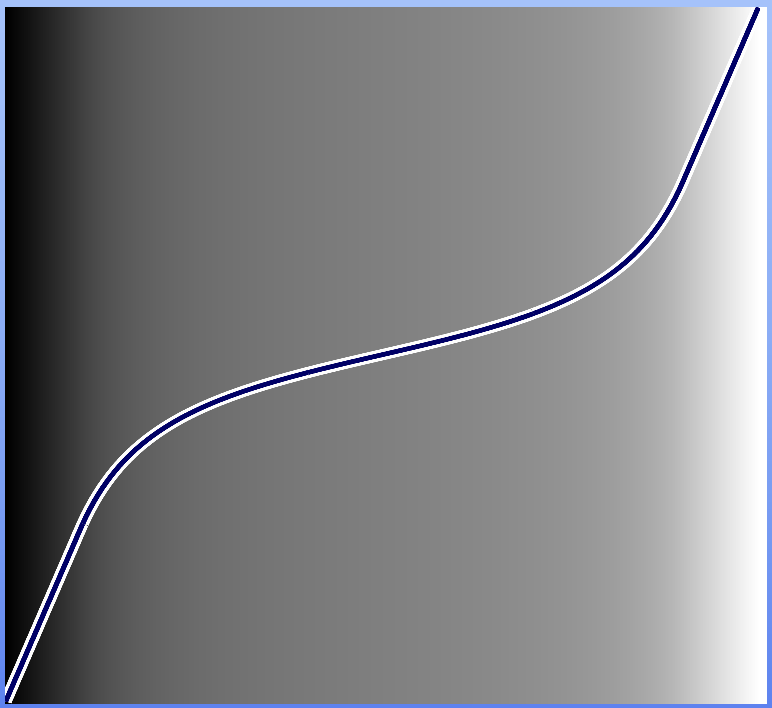
Artifacts of Classical Methods

- A continuously differentiable C^1 transformation avoids false edge artifacts by changing contrast smoothly.



C^0 Linear Spline

T(0)=0, T(10)=25, T(90)=75, T(100)=100



C^1 Rational Quadratic Spline

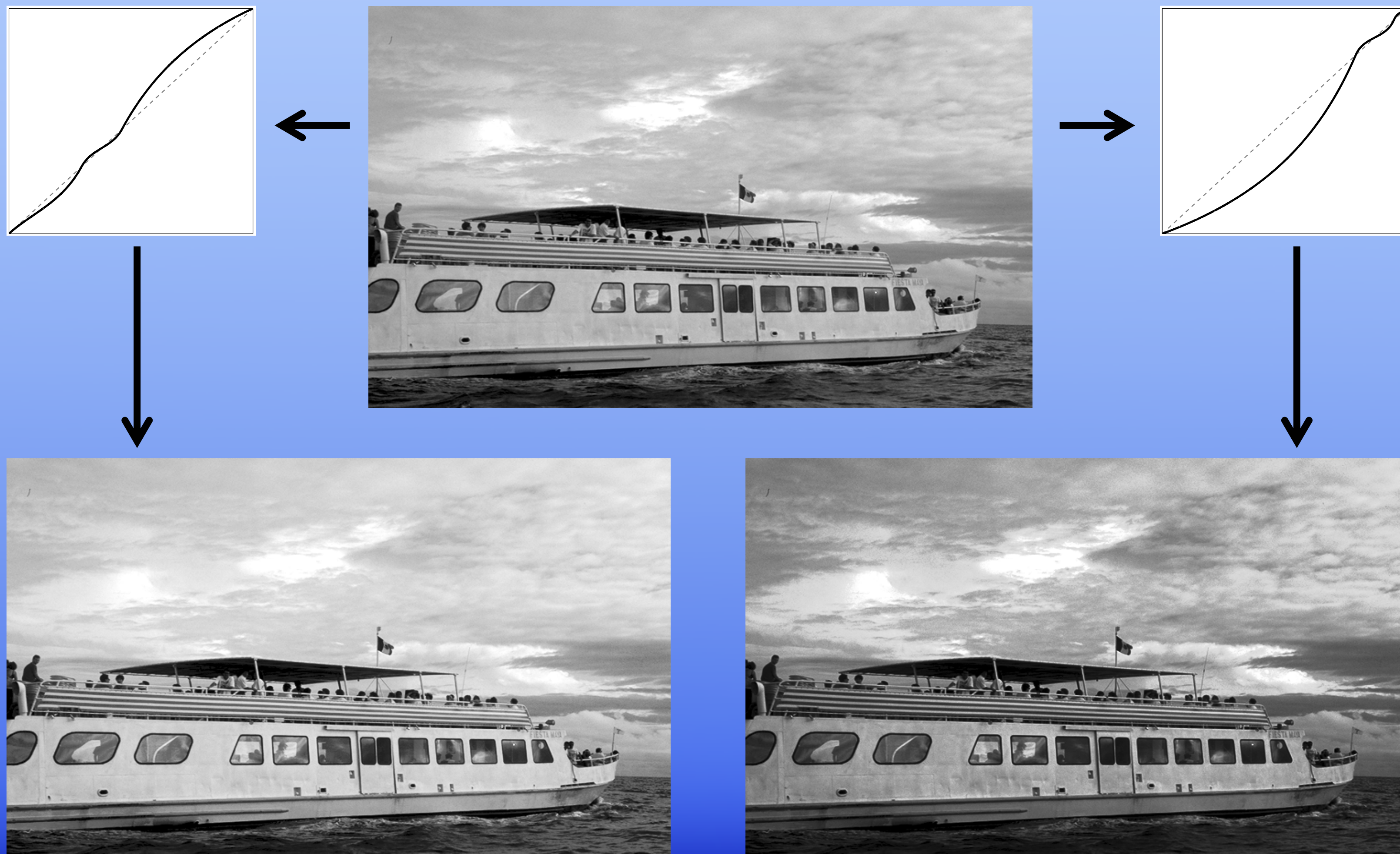
T(0)=0, T(10)=25, T(90)=75, T(100)=100

T′(0)= T′(10)=T′(90)= T′(100)=2.5

Interactive Contrast Enhancement

Motivation

- Since contrast attracts attention, it can convey emphasis.



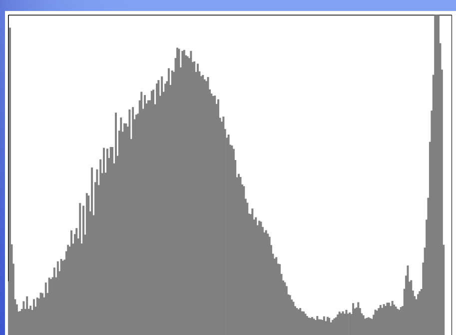
Interactive Contrast Enhancement

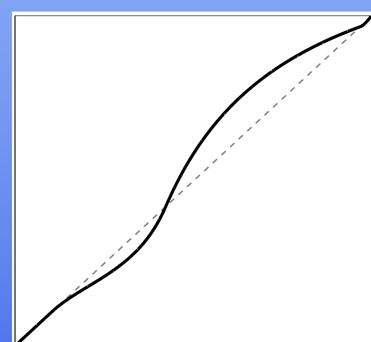
Implementation

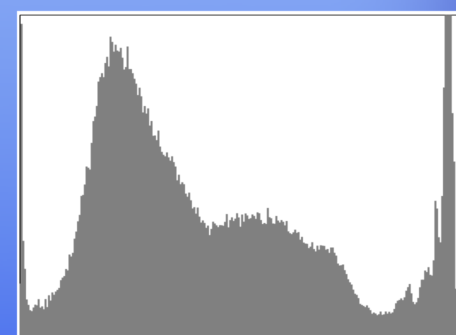
- A quick way to adjust contrast is to click on the picture.
- The user selects the key tones of the image in order to change their contrast d_k without altering their luminance a_k.
  - Where the contrast is raised by increasing $T'(x)>1$, the histogram is stretched, and image details of that tone become more prominent.
  - Where the contrast is lowered by reducing $0<T'(x)<1$, the histogram is compressed, and image details become more subdued.
  - Raising contrast in one region necessitates lowering it in another.
- Histogram warping task: $d_k=T'(a_k)$ subject to $a_k=T(a_k)$.
- The transformation preserves the luminance of the key tones in order to maintain the overall tonal balance of the image.

Interactive Contrast Enhancement

Results

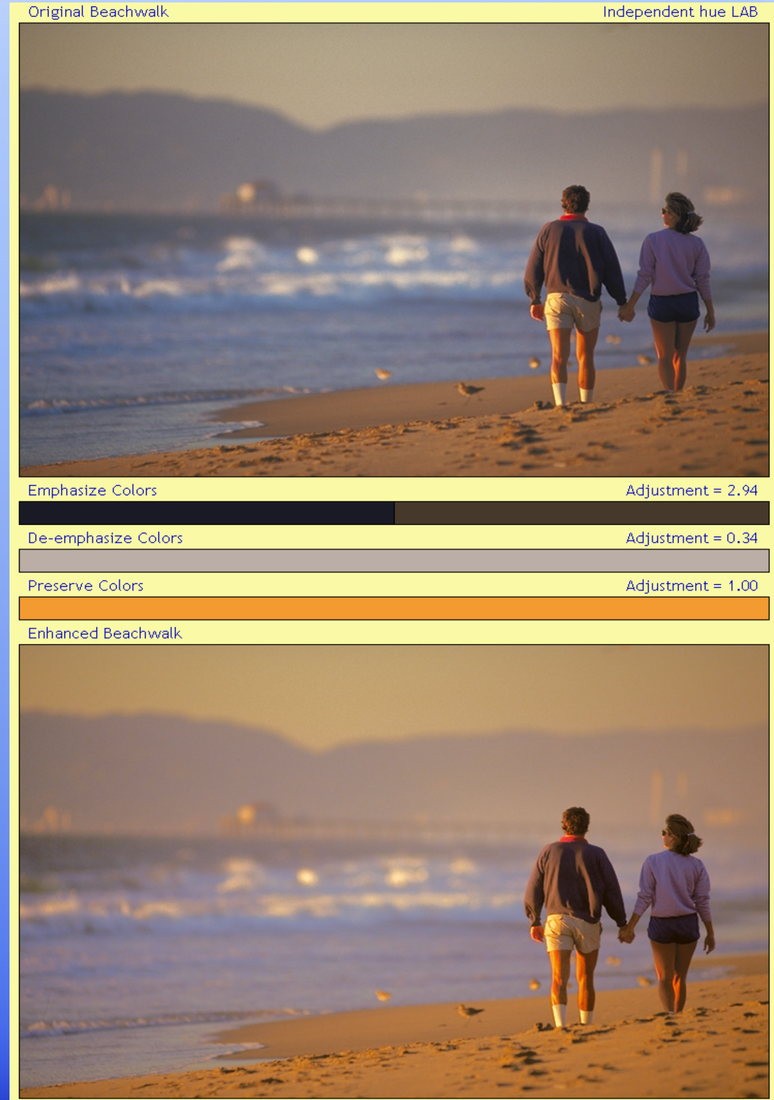






Interactive Contrast Enhancement

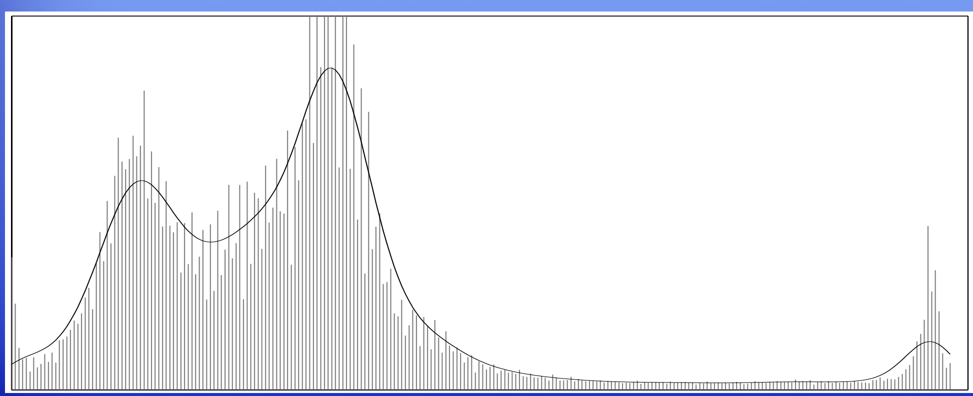
Color Results

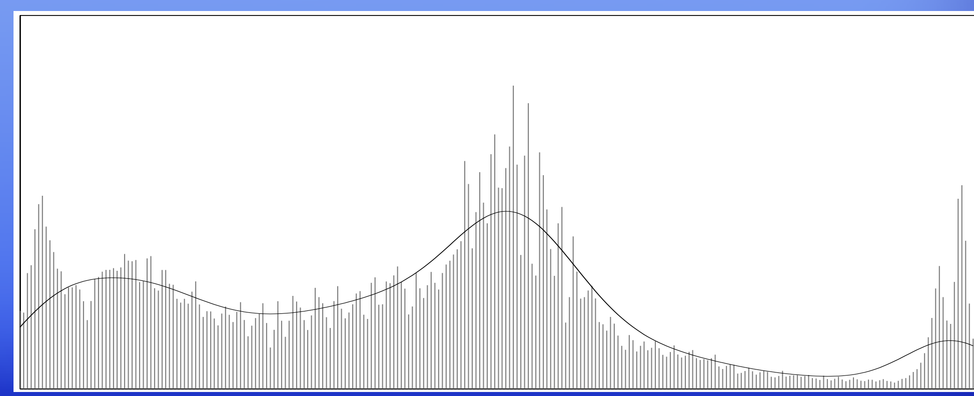


Automatic Contrast Enhancement

Motivation

- Robust contrast enhancement for multimodal histograms.

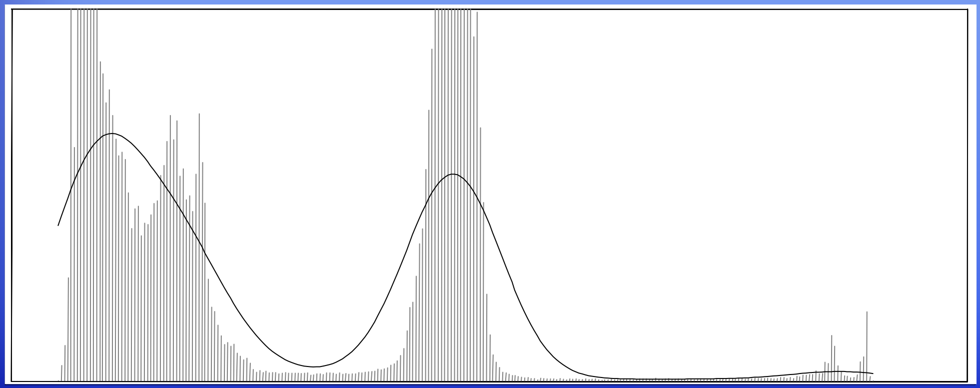


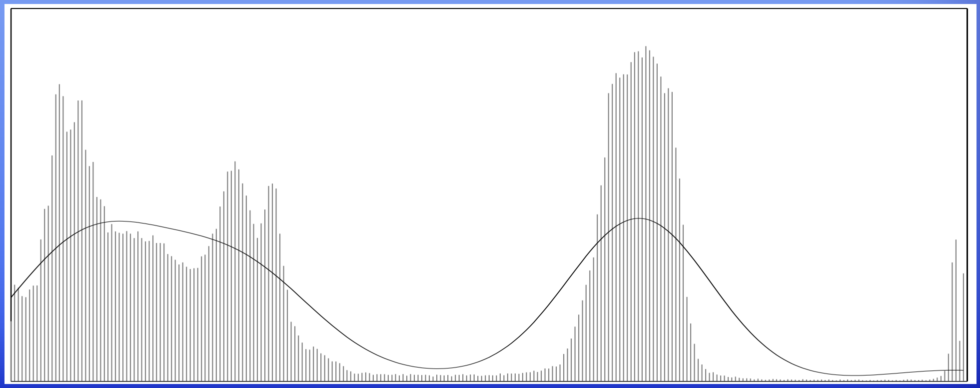


Automatic Contrast Enhancement

Motivation

- Reveal detail in the midtones despite shadows and highlights.





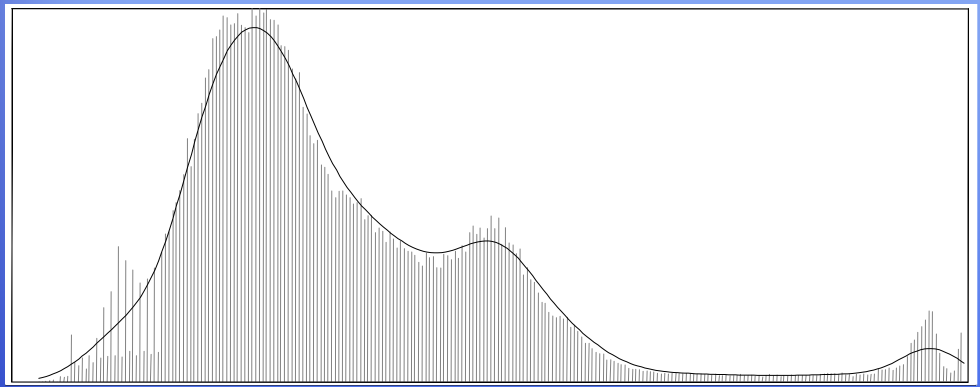
Automatic Contrast Enhancement

Algorithm

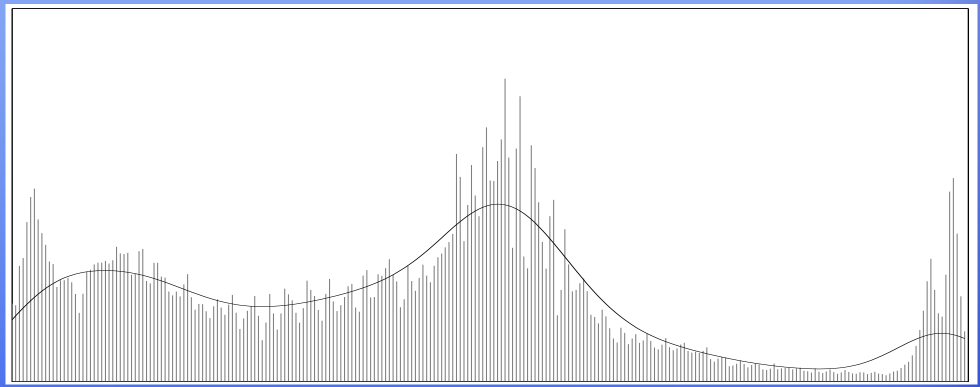
- Contrast is enhanced by spreading out the histogram modes:
  - Apply kernel density estimation to model the tone distribution as a mixture of Gaussians centered on the observations with the bandwidth determined by the maximal smoothing principle.
  - Detect the histogram valleys by finding the critical points of the density estimate, using bisection to locate the zeros of the density's derivative, and, optionally, validate them with the mean shift algorithm to eliminate spurious ripples on plateaus and inflections.
  - Partition the histogram into regions as dictated by the valleys.
  - Displace the midpoint of each histogram region in the direction of the less probable side of its region.
  - Displace the black point and the white point so that these outliers are compressed to give greater prominence to the midtones.
  - Calculate the contrast adjustment at each control point by using a weighted geometric mean of the estimated local left and right slopes of the transformation.

Automatic Contrast Enhancement

Results



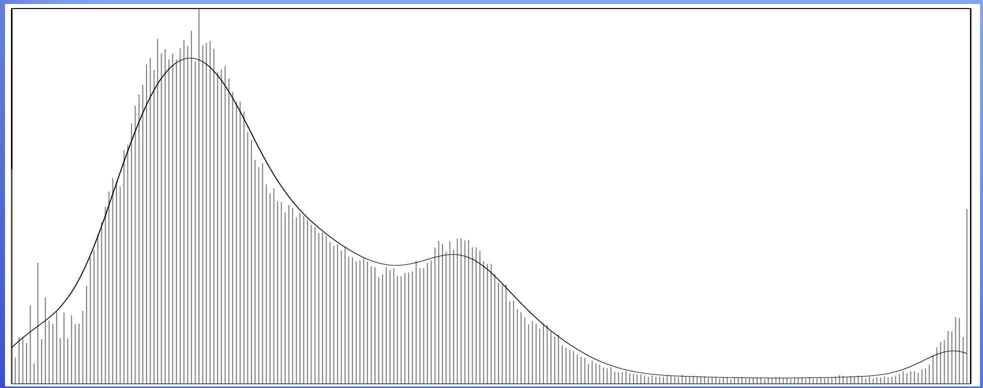
Original Image



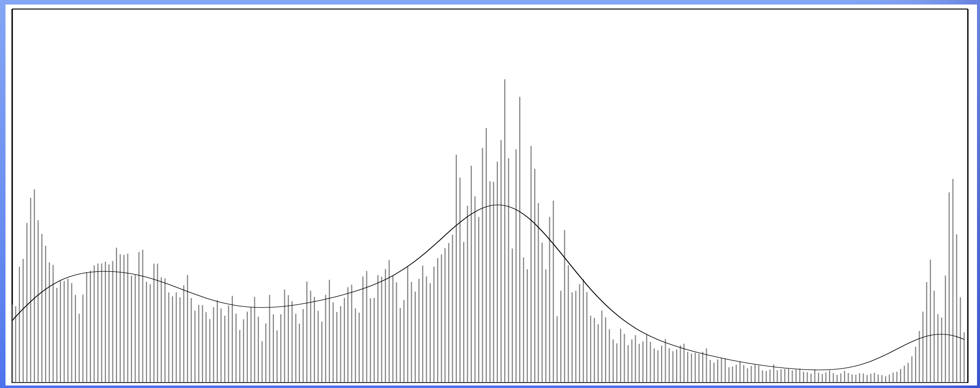
Contrast Enhancement by Histogram Warping

Automatic Contrast Enhancement

Results



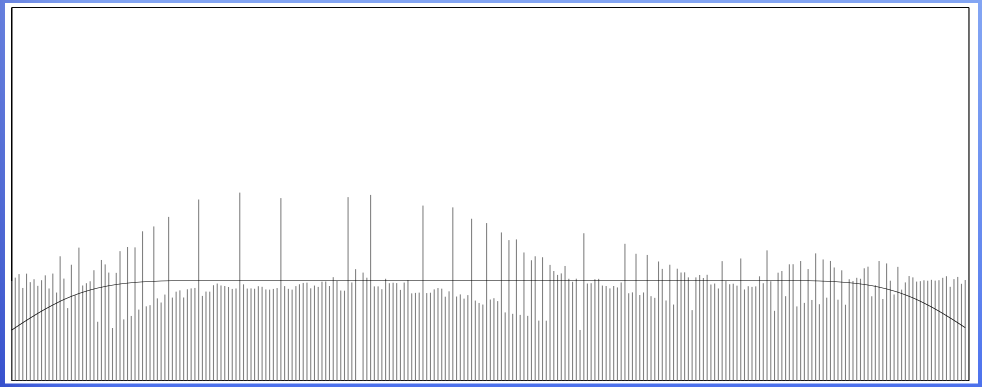
Linear Histogram Stretch

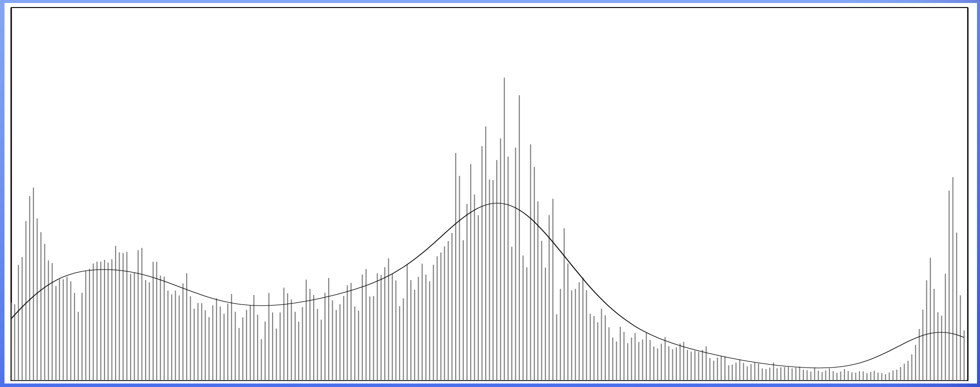


Contrast Enhancement by Histogram Warping

Automatic Contrast Enhancement

Results



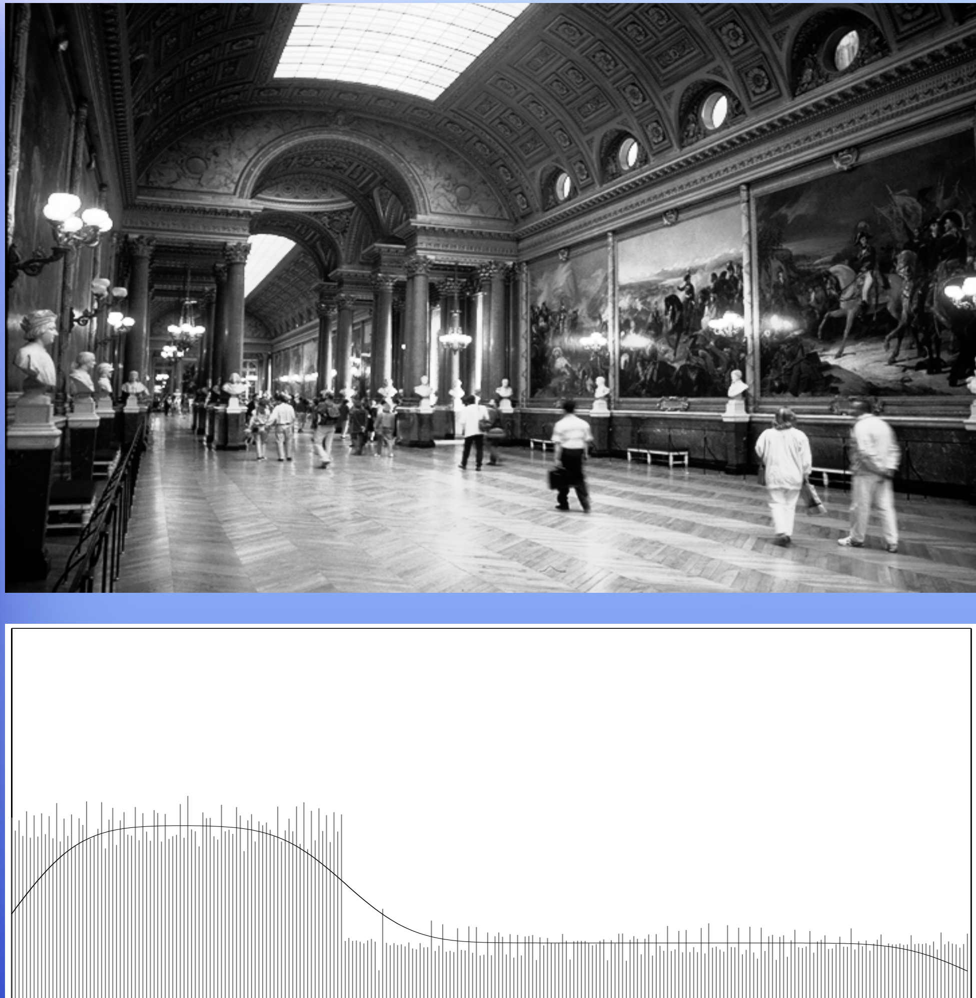


Histogram Equalization

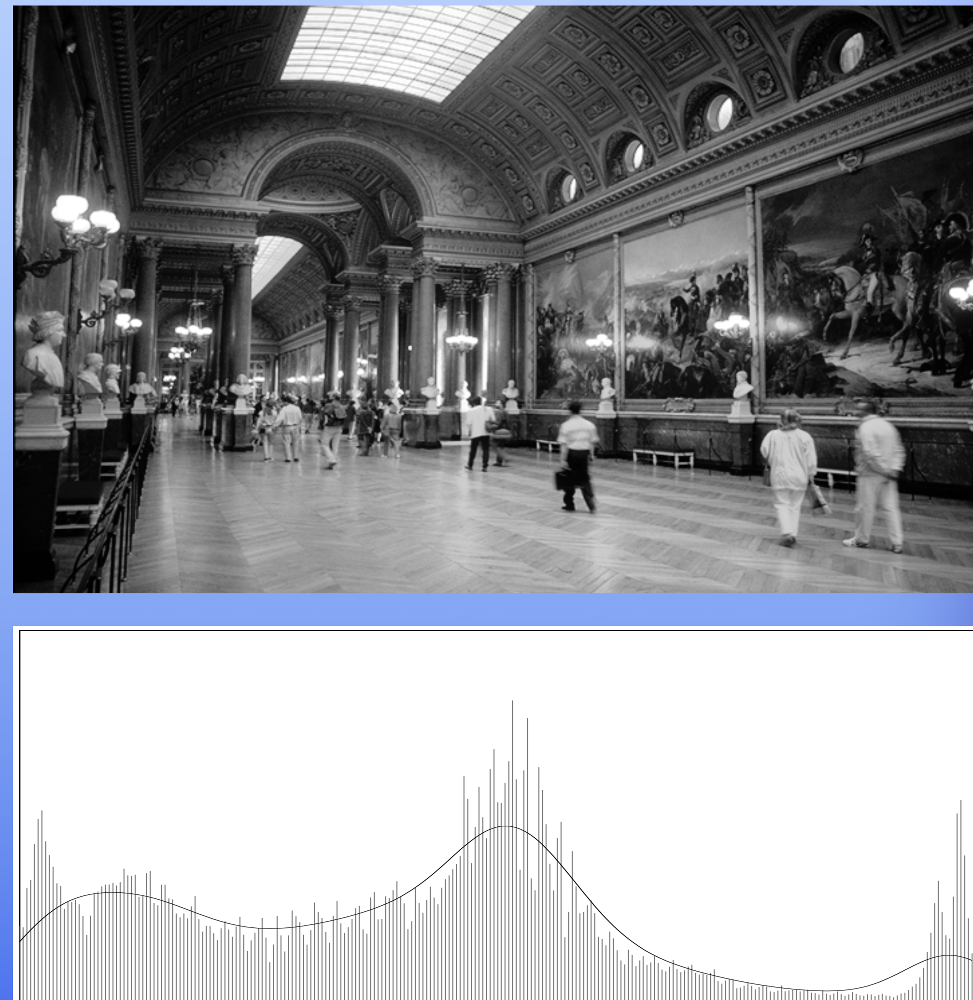
Contrast Enhancement by Histogram Warping

Automatic Contrast Enhancement

Results



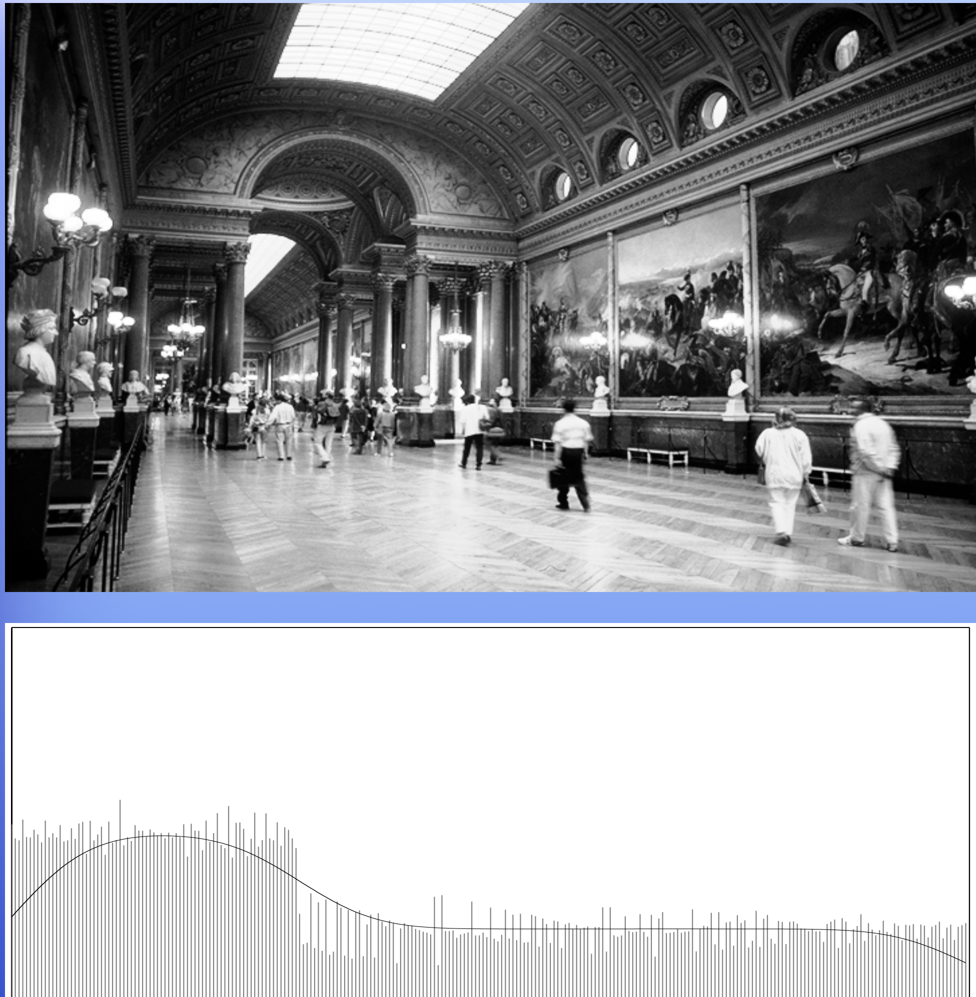
Regional Histogram Equalization
Partitioned by the Mean



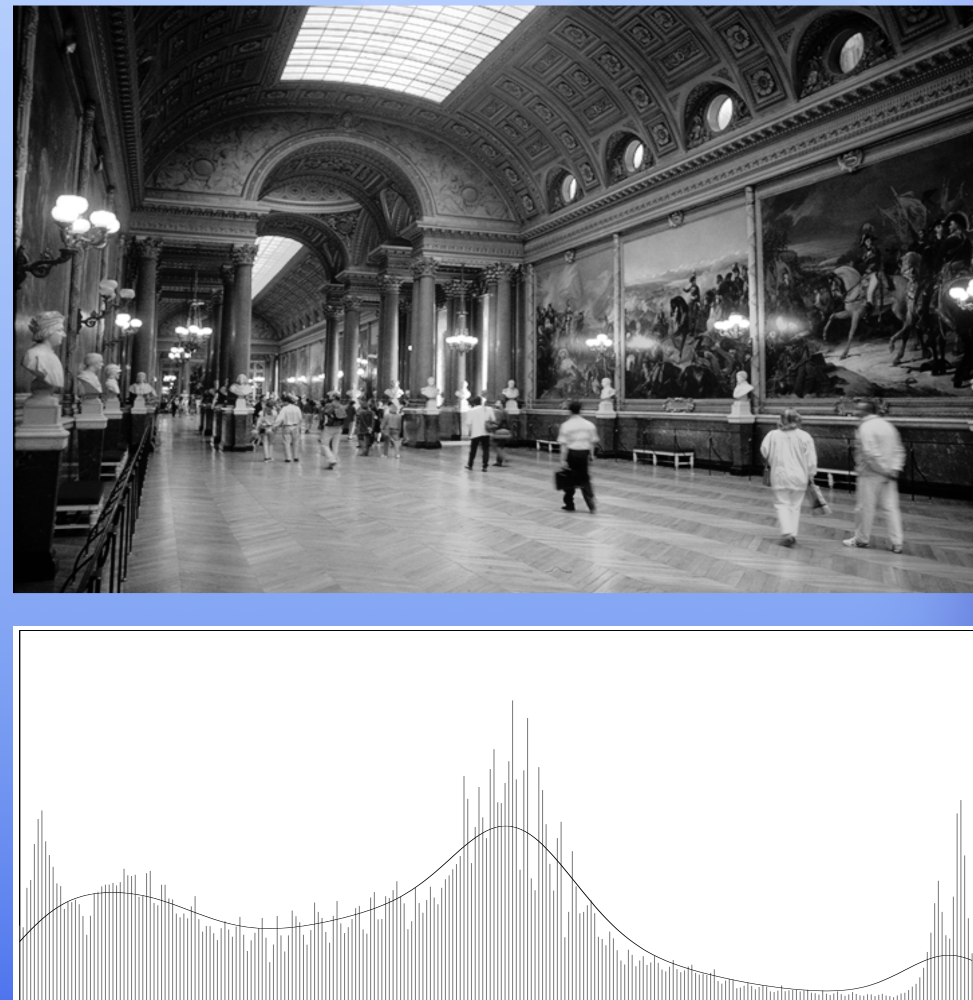
Contrast Enhancement by Histogram Warping

Automatic Contrast Enhancement

Results



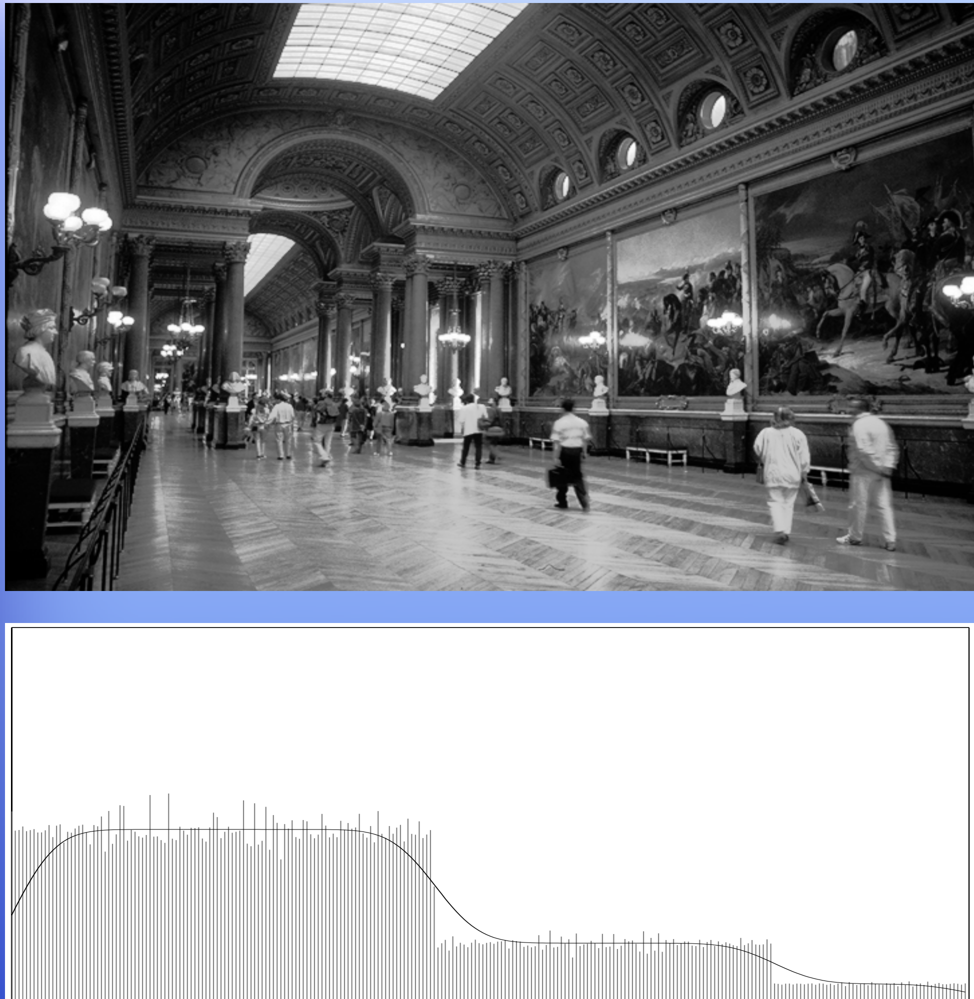
Regional Histogram Equalization
Partitioned by the Median



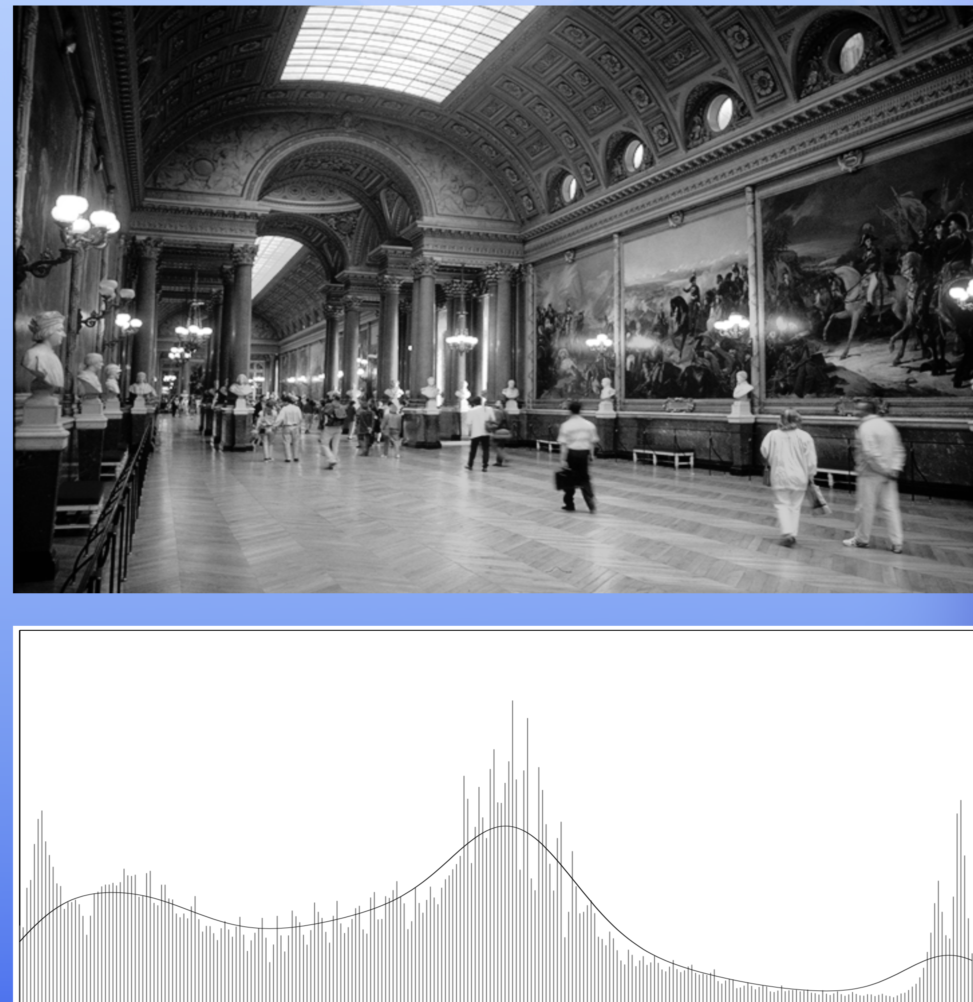
Contrast Enhancement by Histogram Warping

Automatic Contrast Enhancement

Results



Regional Histogram Equalization
Partitioned by the Valleys



Contrast Enhancement by Histogram Warping

Questions?