Adaptive Histogram Equalization (AHE)
and
Contrast Limited Adaptive Histogram Equalization (CLAHE)

Local/Adaptive Histogram Equalization

- HE/HS – studied so far – are global methods, i.e. pixel intensities are modified by a transformation function affected by intensity values of the entire image.

- This approach sometimes does not enhance details in small areas of an image.

- Because the number of pixels in small image areas may have an insufficient influence on the global transformation.

- Solution: devise transformations based on local histograms.

Adaptive Histogram Equalization

- **Input:** Grayscale image I, window size $m \times n$, number of gray levels L
- **Output:** Enhanced image I'
- Algorithm steps:

1. Choose a window size
2. For each pixel (x, y) in the image:
   a. Center the window at (x, y)
   b. Extract local window pixels
3. Compute the local histogram of the window.
4. Compute the local PDF: $p(r_k) = \frac{n_k}{m \times n}$
5. Compute the local CDF:

$$c(r_k) = \sum_{j=0}^{k} p(r_j)$$

6. Apply histogram equalization: $s_k = (L-1)\,c(r_k)$
7. Replace the center pixel with s_k
8. Repeat for all pixels.

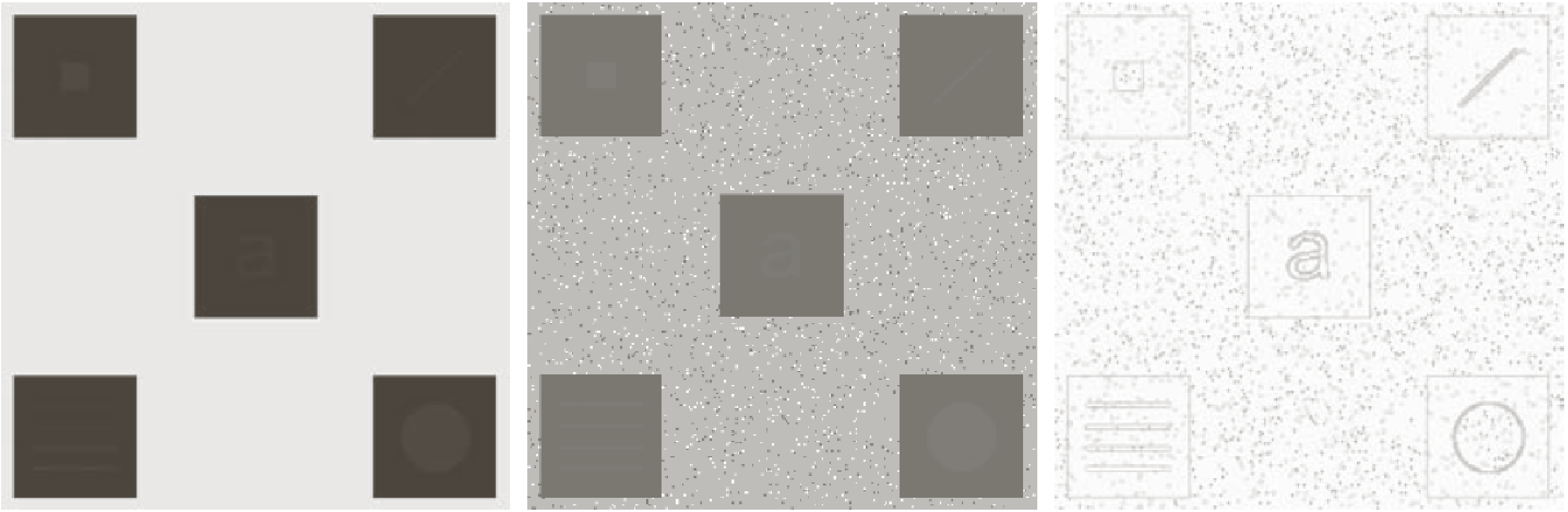
Advantages and Limitations

Advantages:

- Enhances local details
- Handles non-uniform illumination
- Useful in medical and satellite images

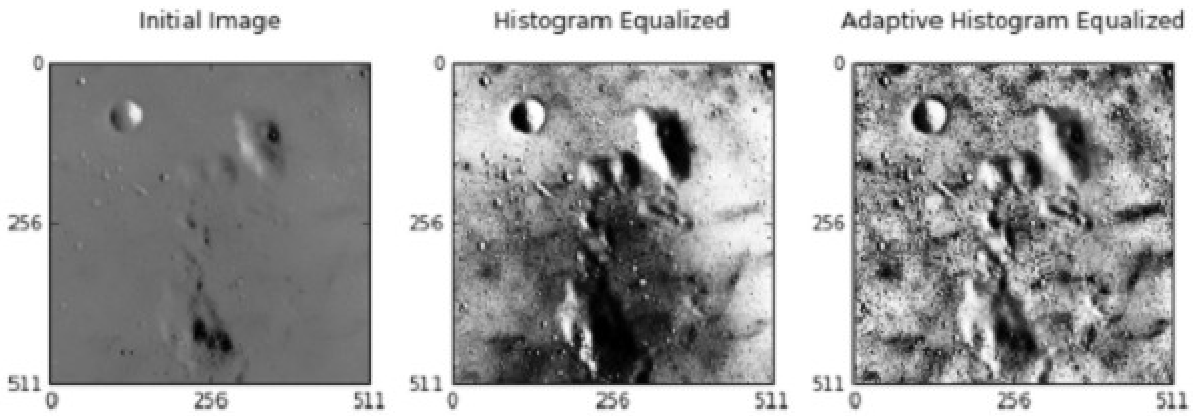
Limitations:

- High computational cost
- Amplifies noise
- Block artifacts may appear



a b c

FIGURE 3.26 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization applied to (a), using a neighborhood of size 3 × 3.



Adaptive means same as local

Original Image

Global histogram-equalized image

Local histogram-equalized image (size 100 x 100)

Local histogram-equalized image (size 50 x 50)

Contrast Limited Adaptive Histogram Equalization (CLAHE)

- Contrast Limited Adaptive Histogram Equalization (CLAHE) is an improvement over Adaptive Histogram Equalization (AHE).
- It enhances local contrast while preventing noise amplification by limiting (clipping) the histogram before equalization.
- The clip limit controls the maximum height of each histogram bin in a local tile.
- Objective is to prevent over-enhancement and noise amplification.
- **Why CLAHE?**
  - AHE may over-enhance noise in uniform regions
  - CLAHE **limits the maximum height of histogram bins**
  - Produces smoother, more natural results

Steps of CLAHE

- Divide the image into small non-overlapping tiles
- Compute histogram for each tile
- Clip the histogram using a clip limit
- Redistribute clipped pixels uniformly
- Apply histogram equalization
- Interpolate between neighboring tiles
- **Advantages of CLAHE**
  - Prevents over-enhancement
  - Reduces noise amplification
  - Minimizes block artifacts
  - Widely used in medical imaging

- Clip limit is often given as a **normalized value** α typically, in **[1, 4]**
- Clip Limit $= \boldsymbol{\alpha} \times \frac{\boldsymbol{m \times n}}{\boldsymbol{L}}$ (how much contrast enhancement is allowed)

Assume:

- Tile size = $4 \times 4 = 16$ pixels
- Gray levels $L = 8$
- $\alpha = 2$

$$\text{Clip Limit} = 2 \times \frac{16}{8} = 4$$

- Each histogram bin is limited to maximum 4 pixels

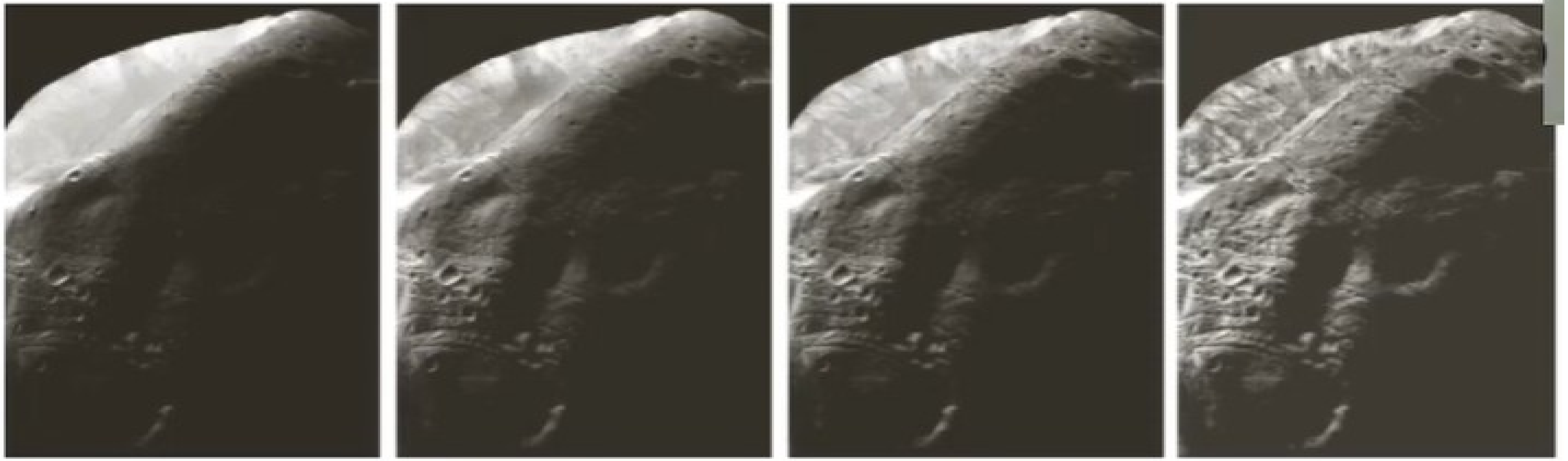
CLAHE Algorithm

1. Divide the image into tiles (e.g., 8×8).
2. For each tile:
   - Compute the histogram.
3. Apply **clipping**:
   - If any histogram bin $> C$, clip it to C.
4. Redistribute the **excess pixels** uniformly across all bins.
5. Compute **PDF** and **CDF** of the clipped histogram.
6. Map gray levels:

$$s_k = (L - 1)\, c(r_k)$$

7. Use **bilinear interpolation** between neighboring tiles to remove block artifacts.
8. Repeat for all tiles.

Performance improvement in CLAHE



a b c d

FIGURE 2.12 (a) Same as Fig. 2.10(a). (b) Result of using function **adapthisteq** with the default values. (c) Result of using this function with parameter **NumTiles** set to **[25 25]**. Result of using this number of tiles and **ClipLimit = 0.05**.

Comparison of HE, AHE and CLAHE

Method	Contrast	Noise	Artifacts
HE	Global	Low	None
AHE	High	High	Yes
CLAHE	Controlled	Low	Minimal