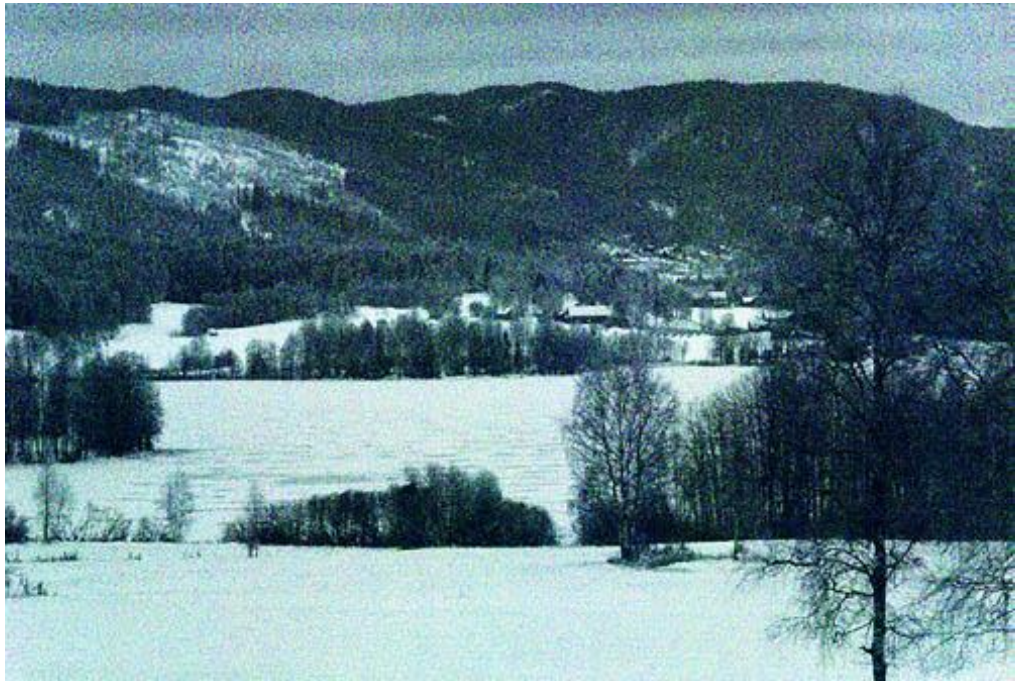
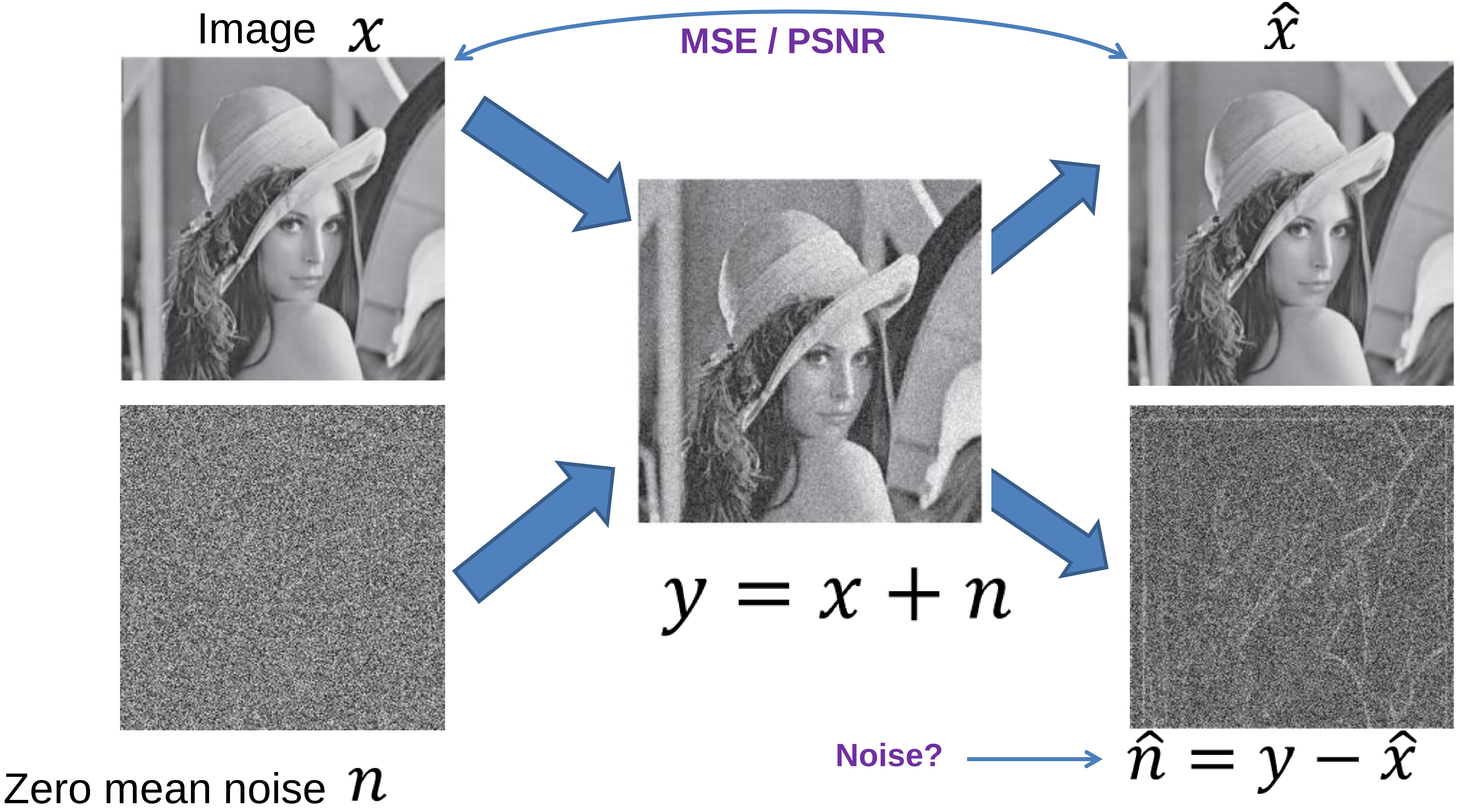
Image Denoising

Beyond Blurring and Median Filtering



Problem Definition: Noise Cleaning



Quality Measures for Restoration

- Given original image $I(x,y)$, restored to $\hat{I}(x,y)$
- In real life $I(x,y)$ is unknown, but known in testing.
- Assumption: Additive White Gaussian Noise (AWGN)

- Mean Square Error

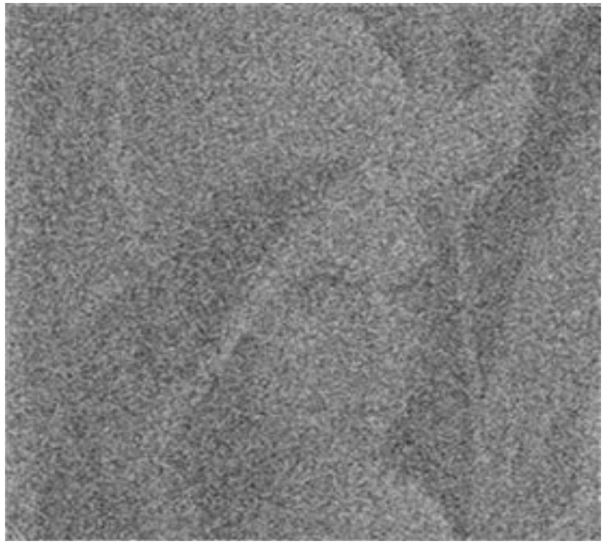
$$MSE = \frac{1}{N^2} \sum_{(x,y)} \left\| I(x,y) - \hat{I}(x,y) \right\|^2$$

- Peak Signal to Noise Ratio

$$\text{PSNR} = 20 log_{10} \frac{255}{\sqrt{MSE}}$$

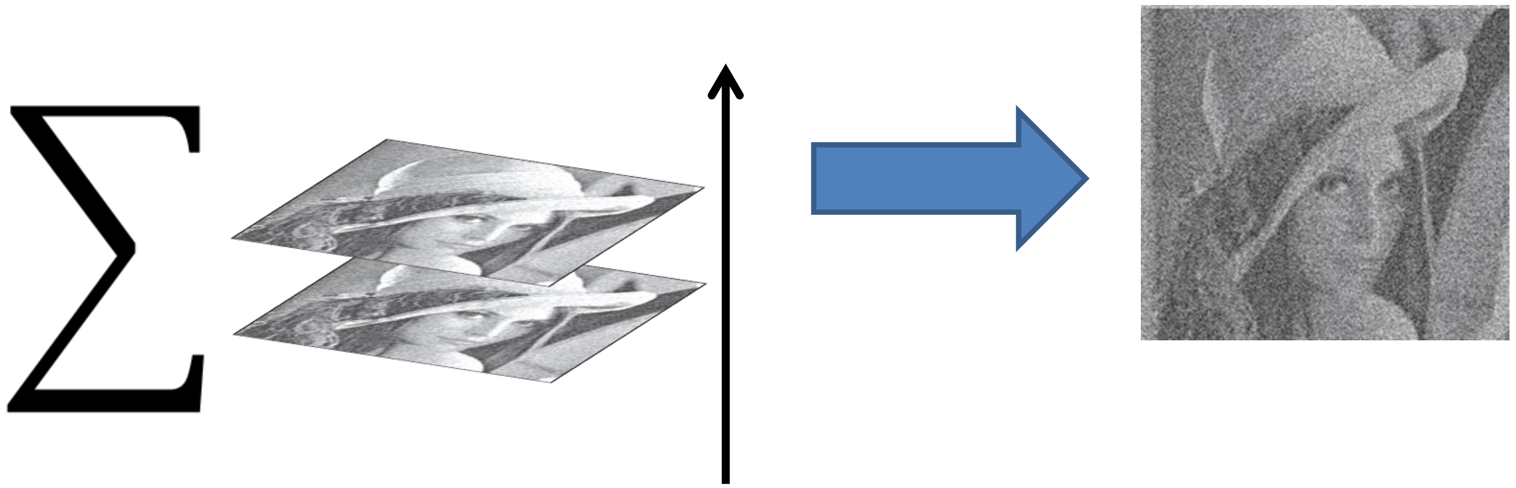
Patch Methods: Non-Local Means Motivation - Temporal perspective

- Assume a static scene, giving a constant signal $x(t)$
- Multiple images $y(t)$ are captured at different times
  $y(t)=x(t)+n(t)$
- Noise $n(t)$ varies over time with zero mean



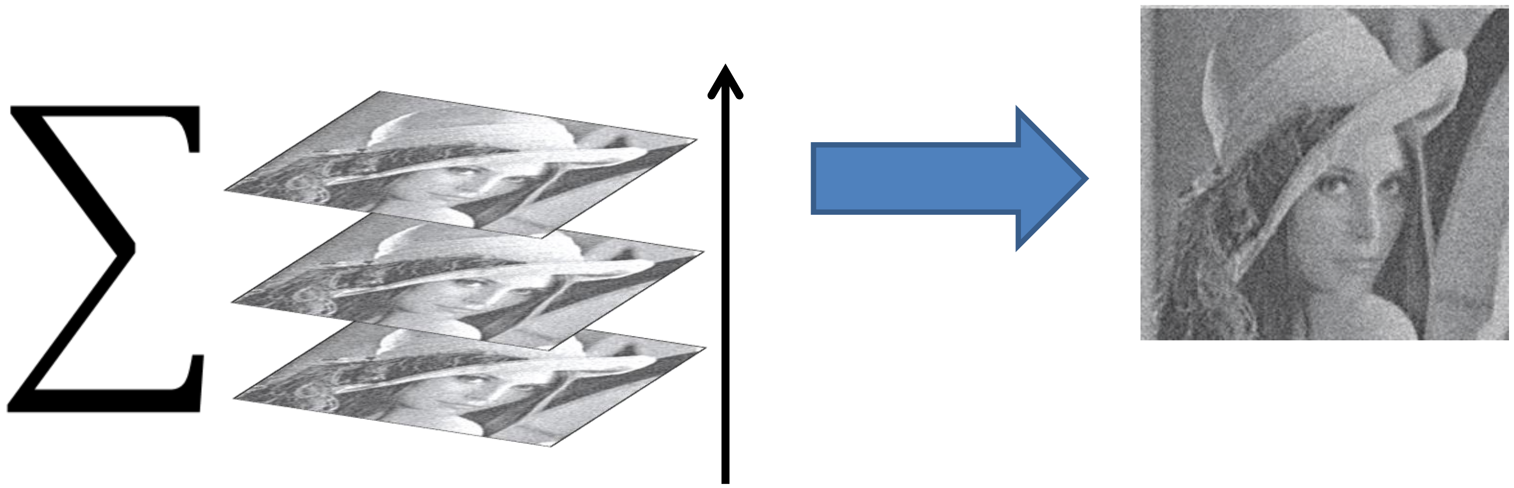
Temporal Denoising

Stationary Images - Average multiple images over time



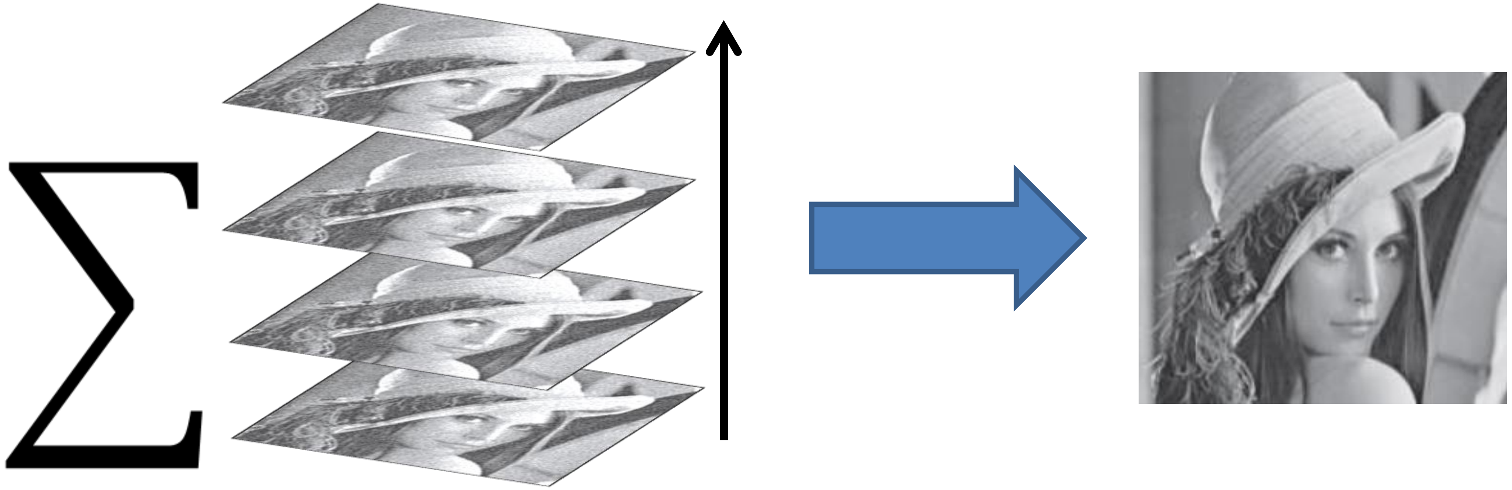
Temporal Denoising

Stationary Images - Average multiple images over time



Temporal Denoising

Stationary Images - Average multiple images over time



It works because (i) the noise is zero mean

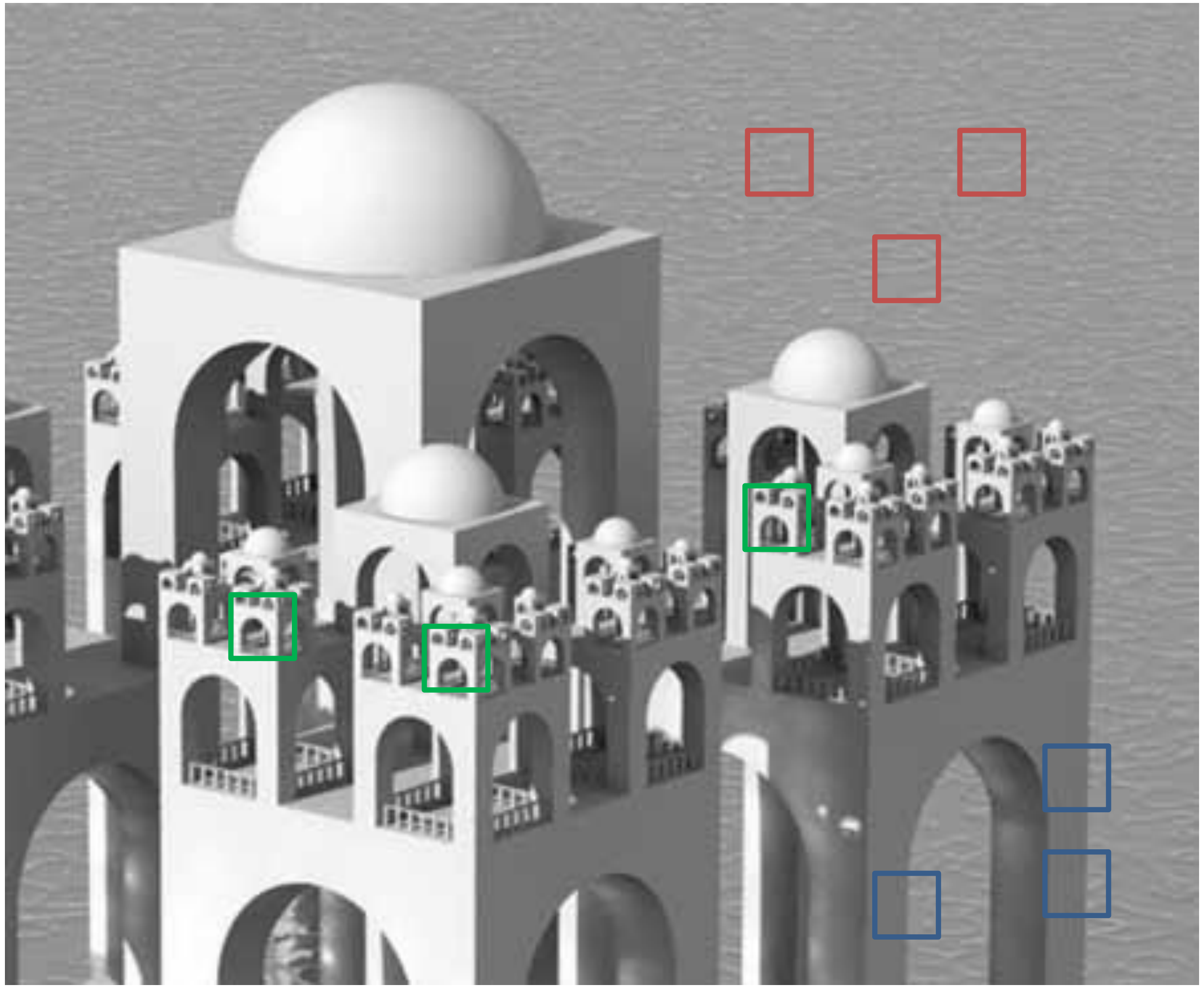
(ii) When variance of each variable $\{X_i\}_{i=1}^{n}$ is σ^2,

the variance of their average is σ^2/n

$$Var(\bar{X}) = Var\left(\frac{1}{n}\sum_{i=1}^{n} X_i\right) = \frac{\sigma^2}{n}$$

Redundancy in Natural Images

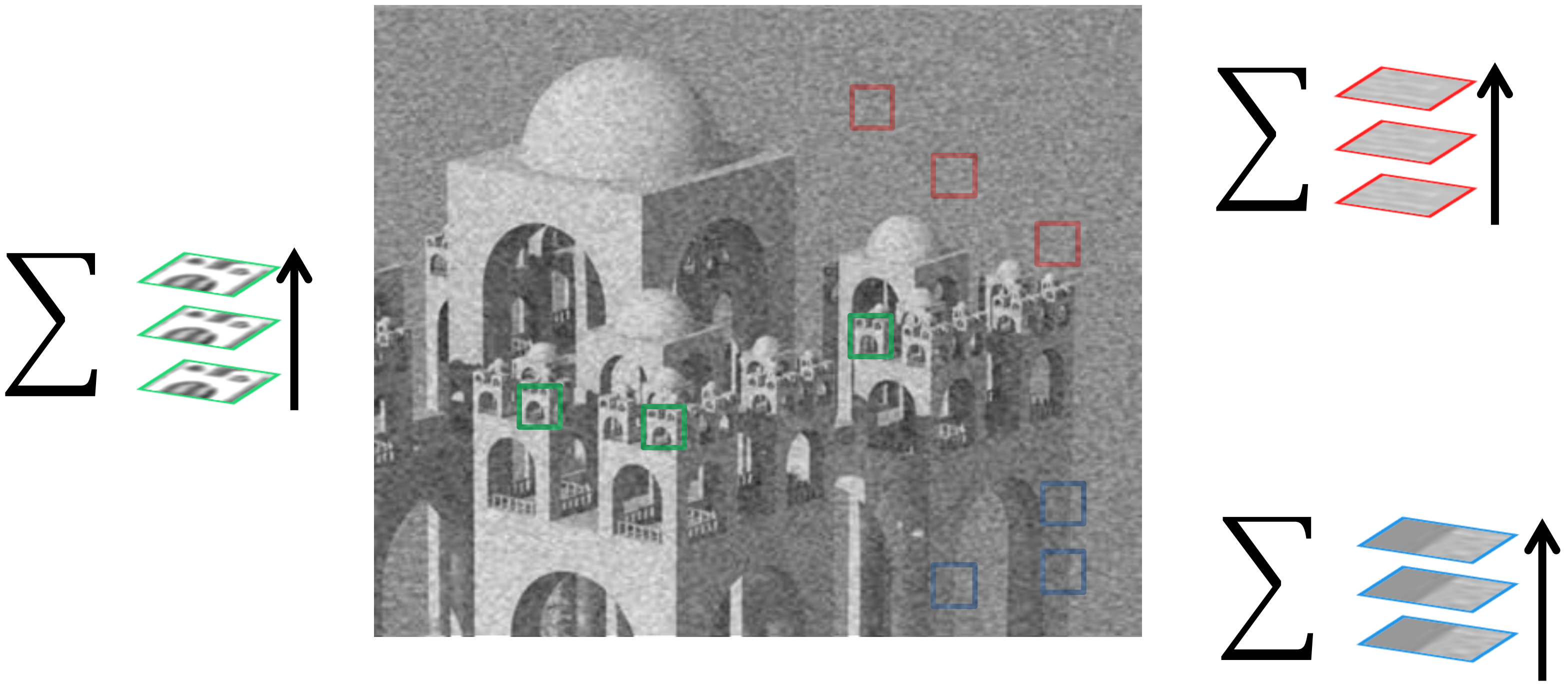
Many image patches are similar



Glasner & Irani (2009)

Single Image Denoising

Find and Average Similar Patches

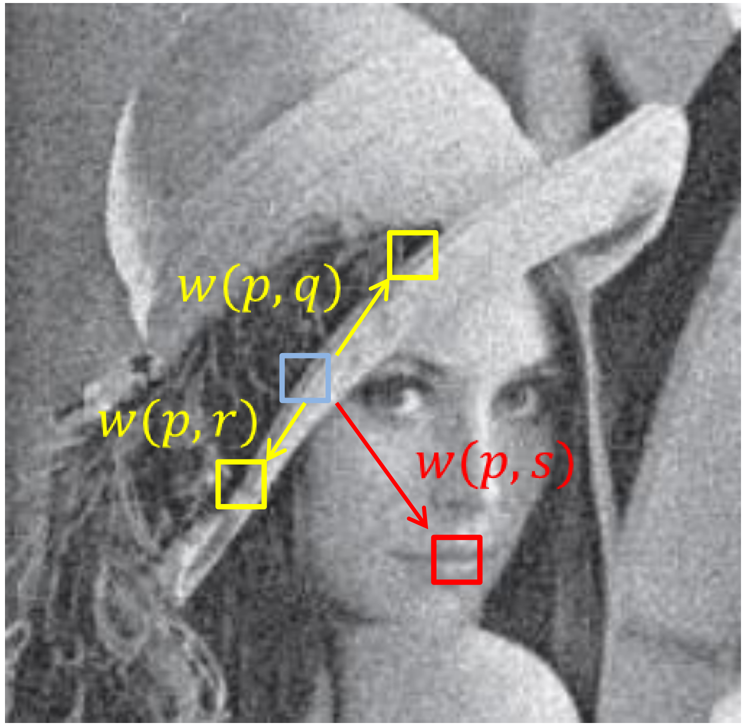


Use weights as patches are not identical

Non-Local Means (NLM)

- Given one pixel, compute the similarity of a patch around it to patches around **all other** pixels.
- Compute a weighted average of **pixels** based on patch similarity.
- Replace pixel value by this average

$$\hat{x}\,(m,n) = \frac{1}{C(m,n)} \sum_{i,j} y(i,j) \underbrace{e^{-(SSD(N(m,n)-N(i,j))}}_{w_{mnij}}$$



y is input image, $\hat{x}$ is output image,

$N(i,j)$ is a neighborhood around pixel (i,j)

Non-Local Means Equation

$$\hat{x}\,(m,n) = \frac{1}{C(m,n)}\sum_{i,j} y(i,j)w(m,n,i,j)$$

$$w(m,n,i,j) = e^{-\frac{SSD\,(N(m,n)-N(i,j))}{2\sigma^2}}$$

- The pixel value at location (m,n) is the average of all other pixels (i,j) in the image, weighted by $w(m,n,i,j)$
- The weights are computed from Sum of Square Differences(SSD) between neighborhoods of (m,n) and of (i,j), $N(m,n)$ etc.
  - SSD can have equal weights for all pixels in $N(m,n)$
  - Or: Gaussian weights, where center pixel has higher weight
  - Or: neighborhoods can be normalized by mean and variance

Patch Based Noise Cleaning Methods

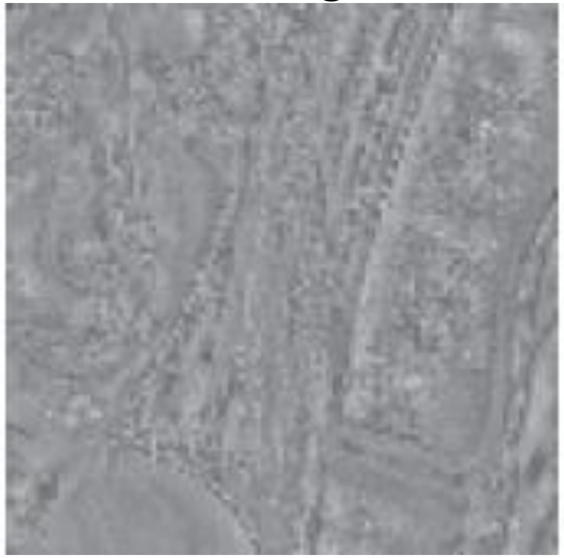
- NLM is one of a family of patch-based noise cleaning methods
- Variations include: Other similarity measures between patches, replacing the SSD
- Define search areas for patches, E.g. search also in other frames (Google's Night-Sight)
- Methods to replace averaging, E.g. Multi-frame super-resolution (Google's Night-Sight)

Comparison

Difference Between Noisy and Denoised

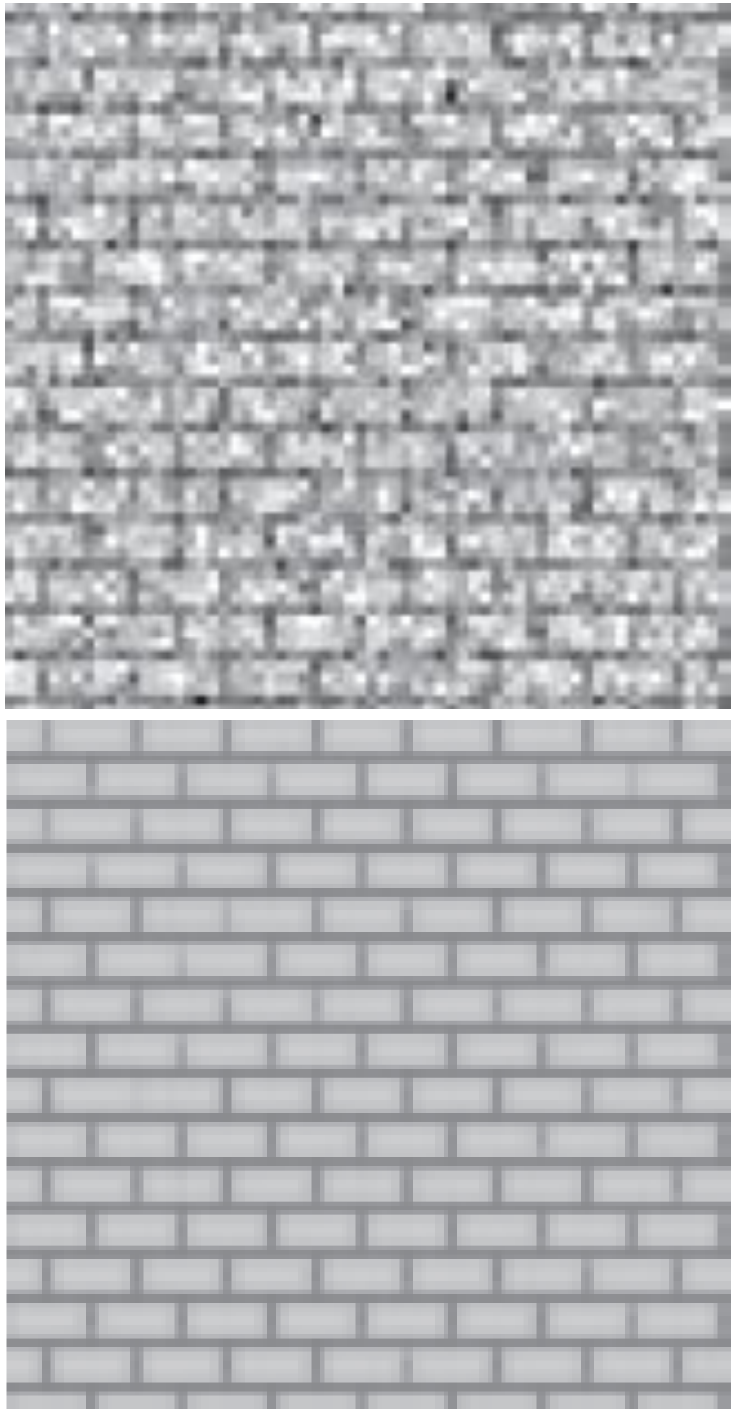
Gaussian Smoothing

Bilateral Filtering



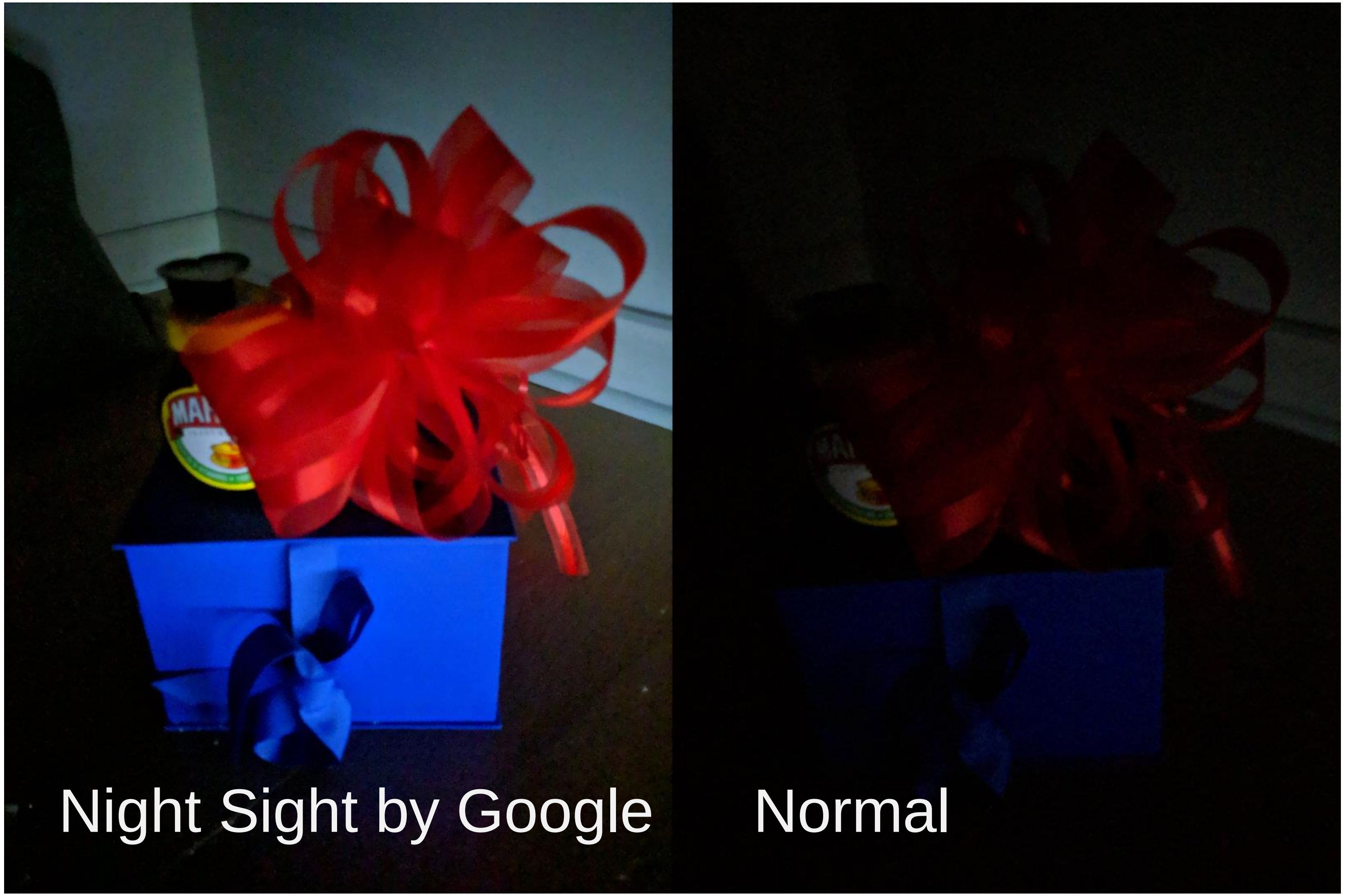
NLM

NLM

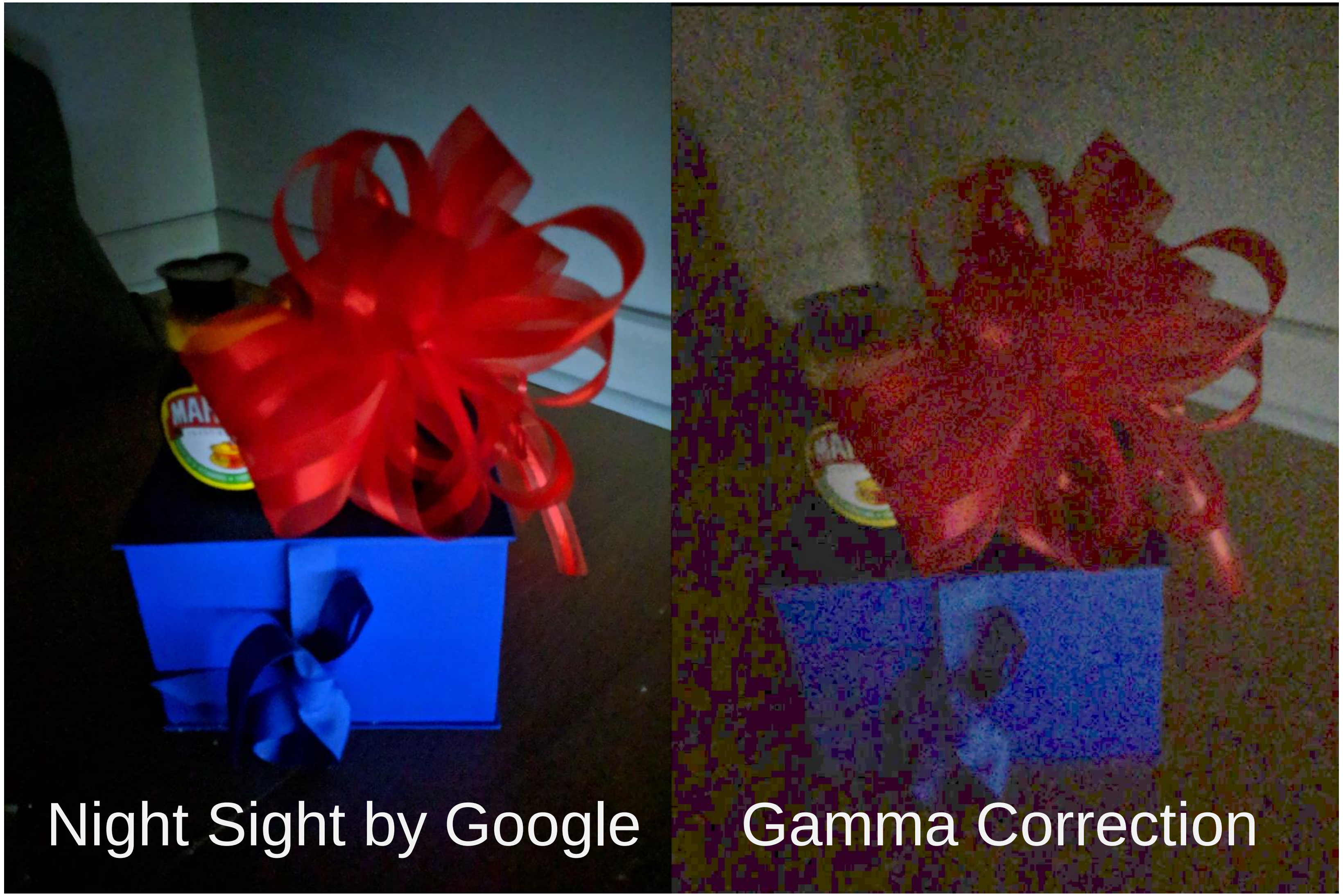


NLM

"GOOGLE Gives the Pixel Camera Superhuman Night Vision" 14/11/18



Increasing Lightness by Gamma Correction



Google's "Night Sight" Process by **Yael Pritch**

- Low light traditional approach: ~~Use very long exposure~~
- Take multiple pictures, 6 Sec. (6-15 pictures)
- Exposure time determined from motion (gyro & OF, Next…)
- Before averaging: Perform alignment between pictures to compensate for motion (Next in course)
- Combine overlapping patches using Multi-frame Super-resolution approach (Read…)
- Color Correction ("White Balance" – Read…)
- Problem: How to focus?

Night Sight – Lights & Projector Off