

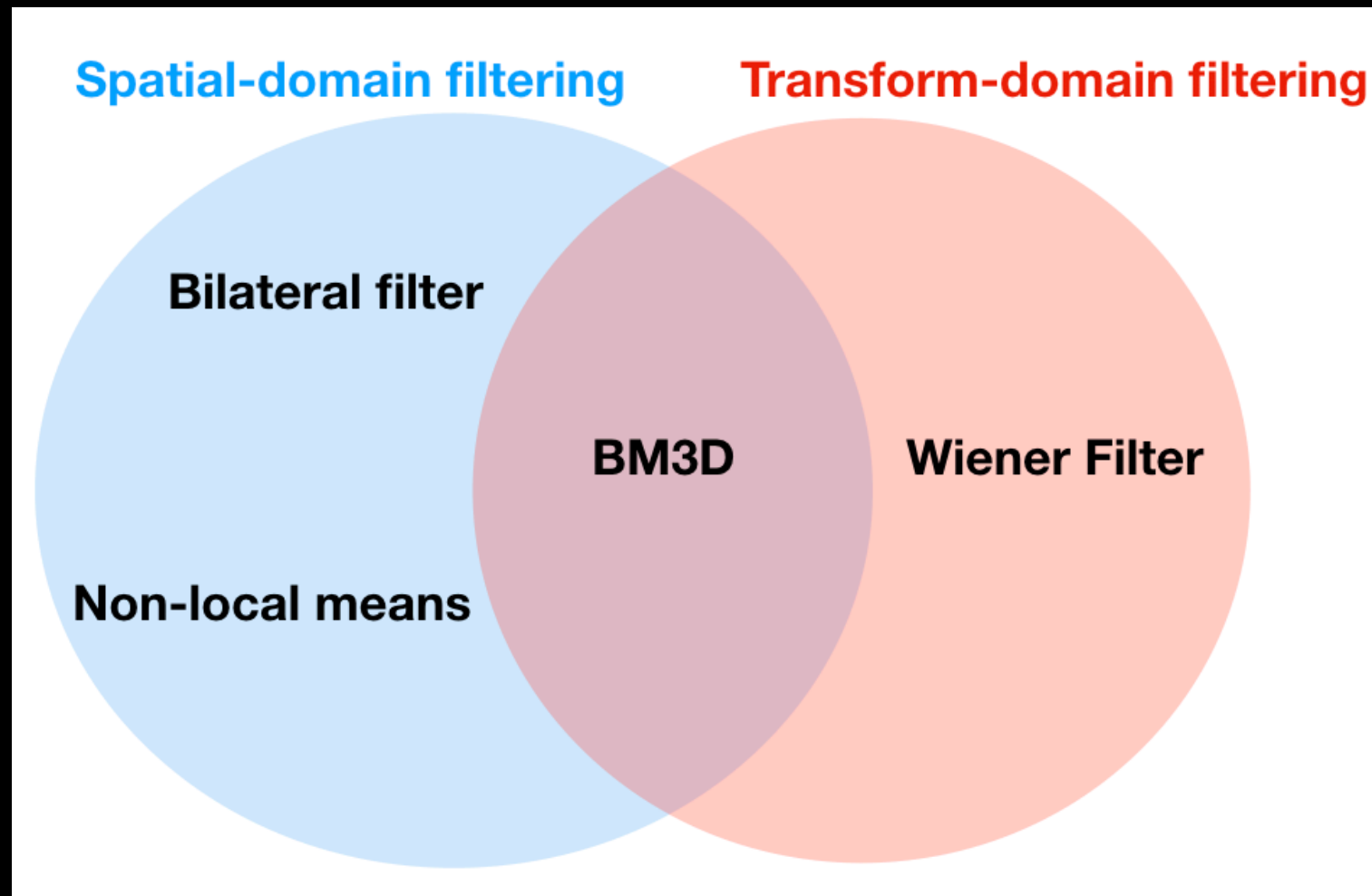
# Tutorial 11:

# BM3D

Digital Image Processing (236860)



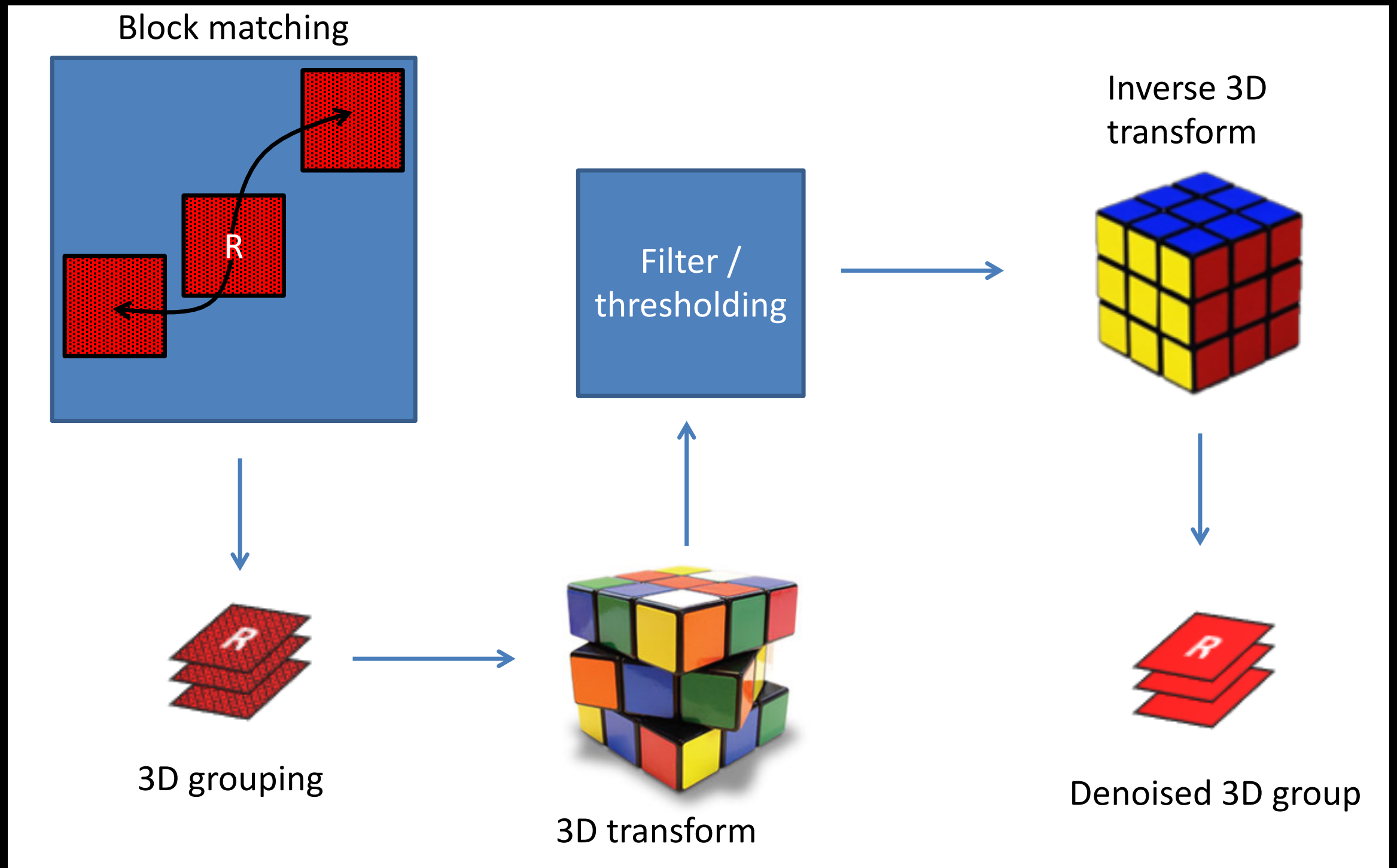
# Image denoising



# BM3D

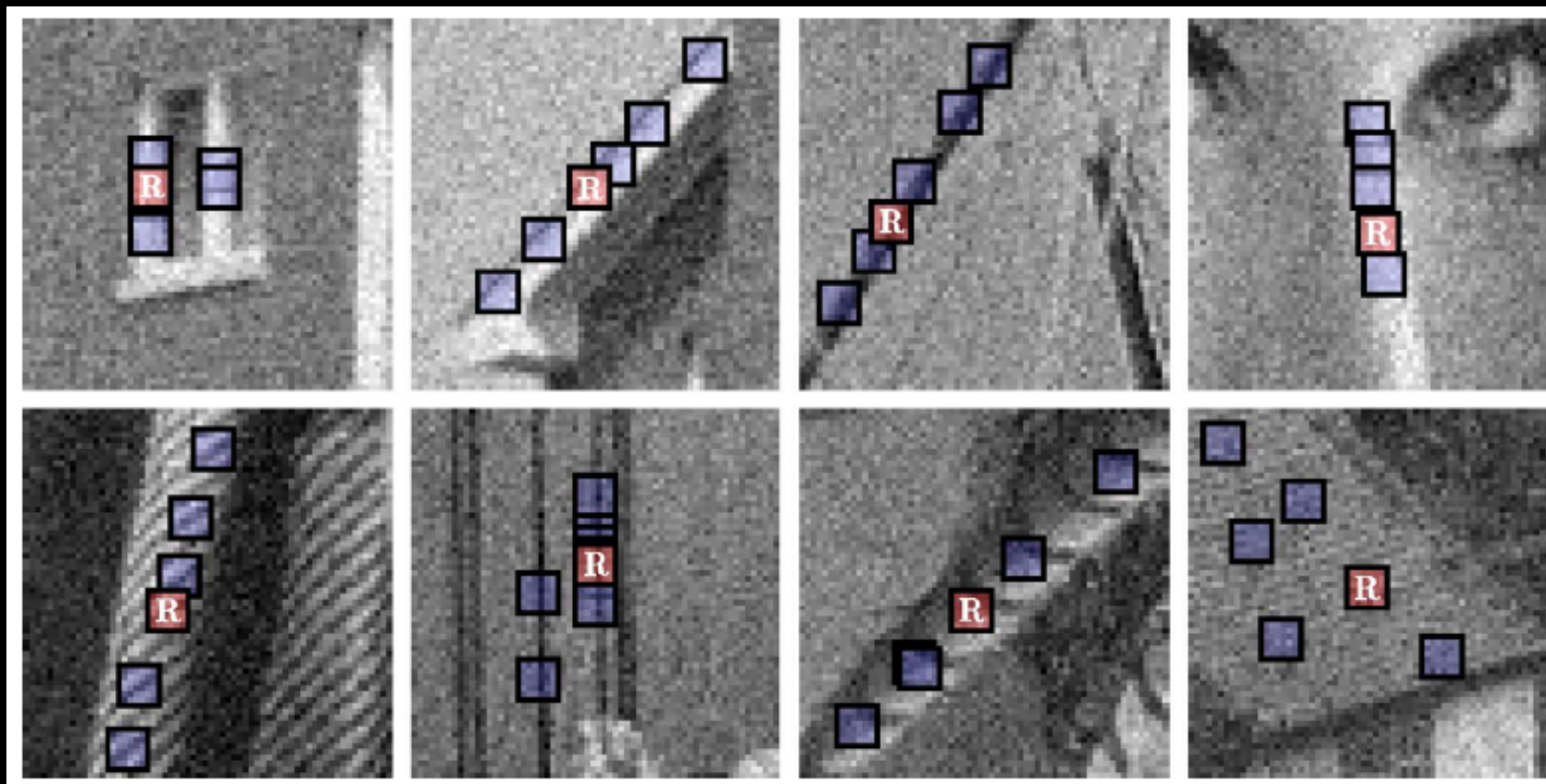
- Block Matching 3D Collaborative Filtering
- Ideas:
  - Group similar patches (BM)
  - Jointly denoise each group (3D)
  - Smart fusion of the estimates

# Scheme



# Grouping by block matching

- For every reference block:
  - Calculate SSD (sum of squared differences) between it and all other blocks
  - If  $SSD < \text{Threshold} \Rightarrow$  add it to the group



# 3D Transform

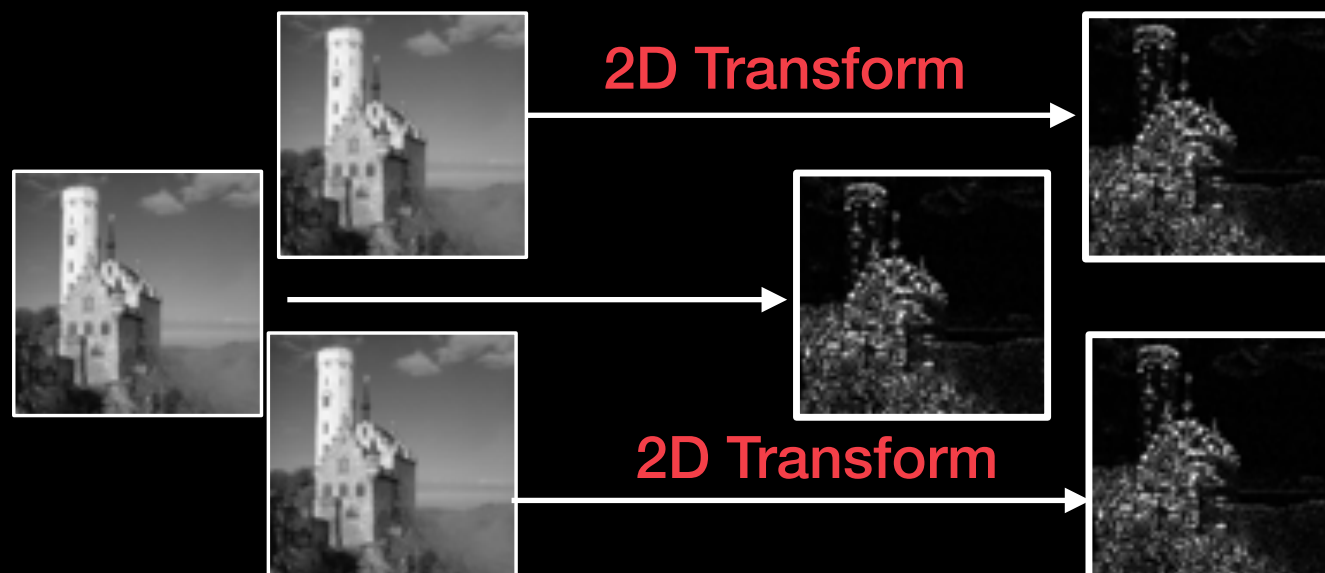
Reminder:



Sparsity induced

$\alpha$

Naive:



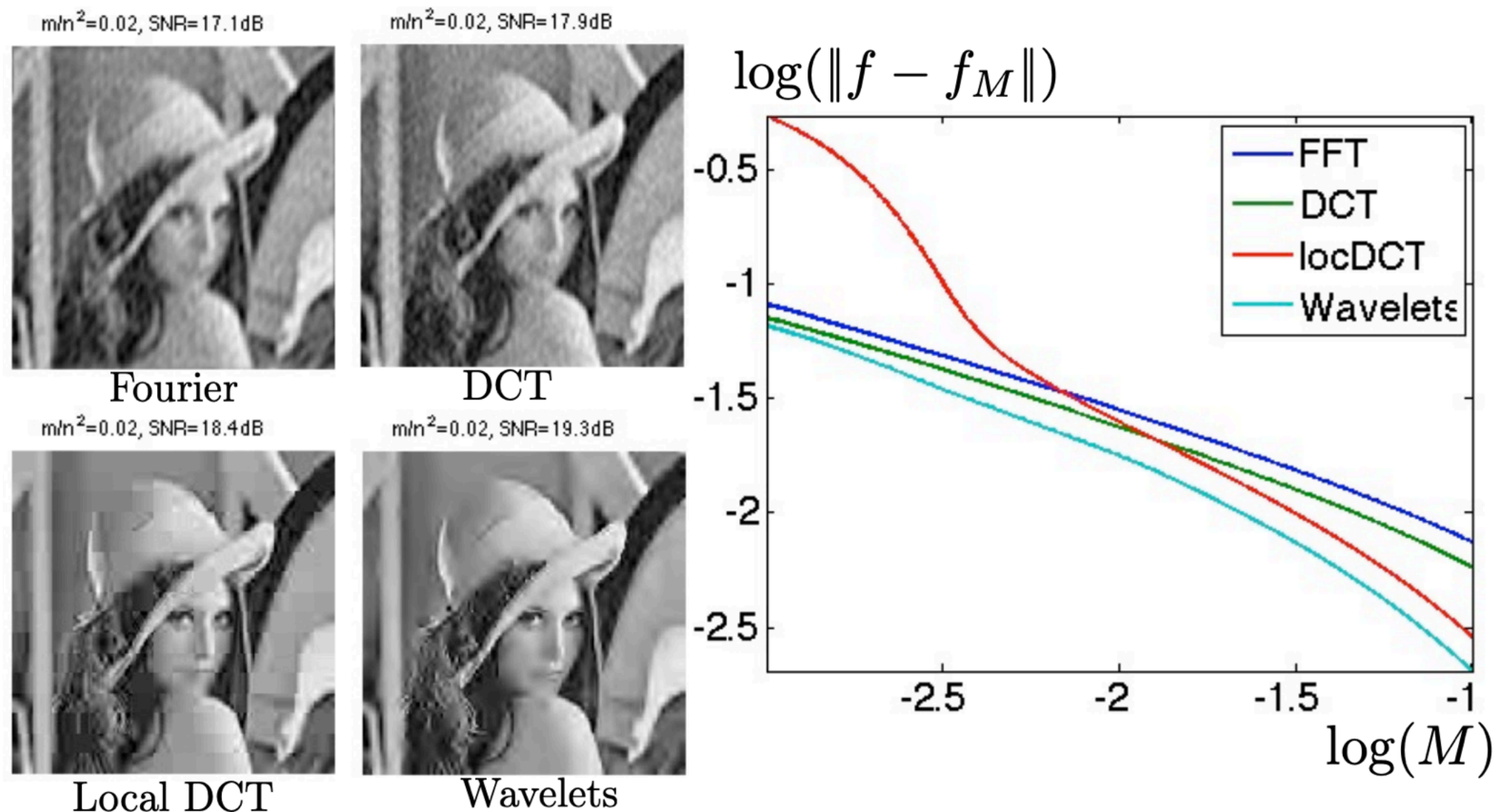
$k\alpha$

BM3D:



$\alpha$

# Which transform?

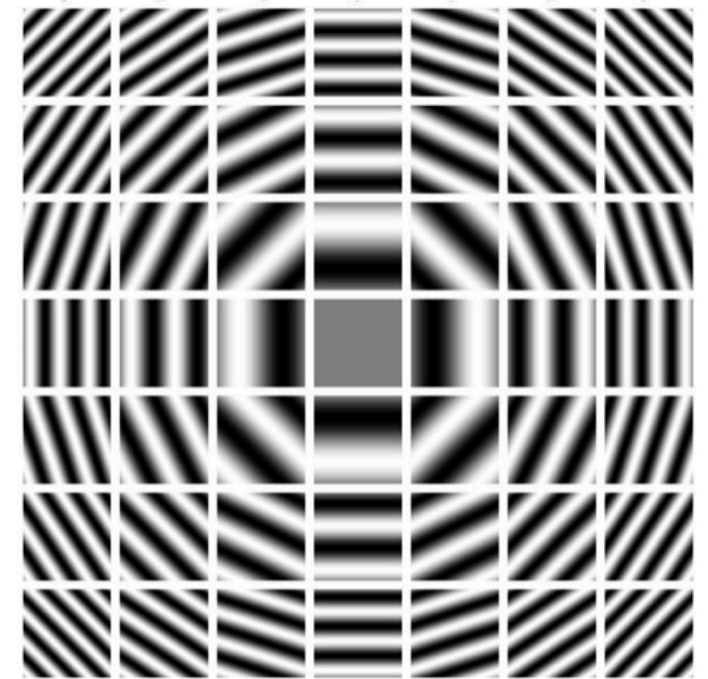


Best basis  $\iff$  Fastest error decay  $\|f - f_M\|^2$



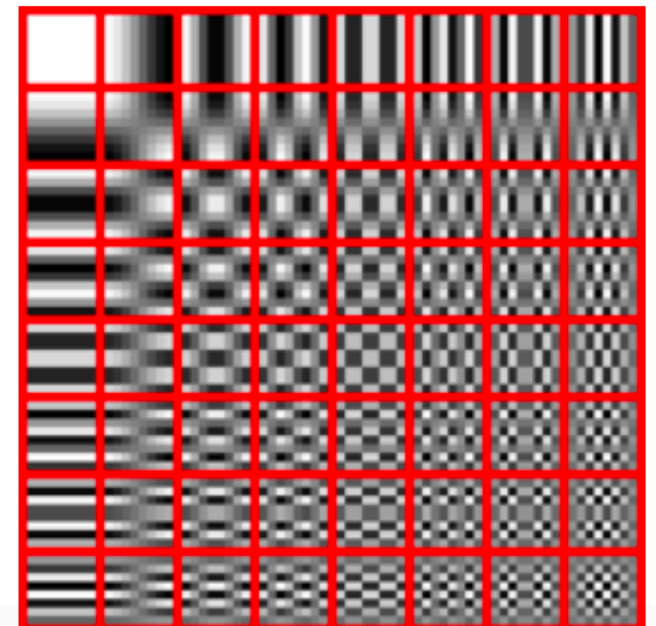
# DFT vs. DCT

$$\begin{aligned} X_k &= \sum_{n=0}^{N-1} x_n \cdot e^{-\frac{2\pi i}{N} kn} \\ &= \sum_{n=0}^{N-1} x_n \cdot [\cos(2\pi kn/N) - i \cdot \sin(2\pi kn/N)], \end{aligned}$$



$$X_k = \sum_{n=0}^{N-1} x_n \cos \left[ \frac{\pi}{N} \left( n + \frac{1}{2} \right) k \right] \quad k = 0, \dots, N-1.$$

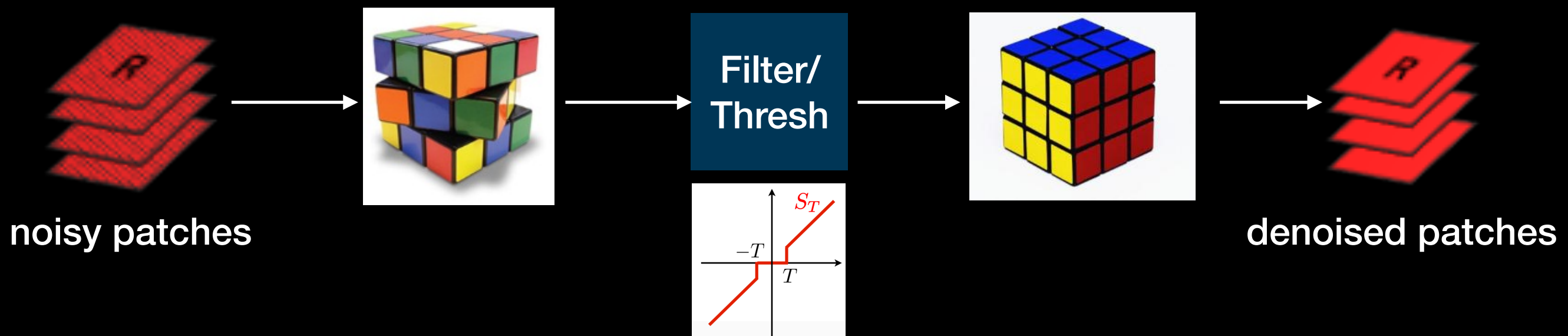
Used in JPEG



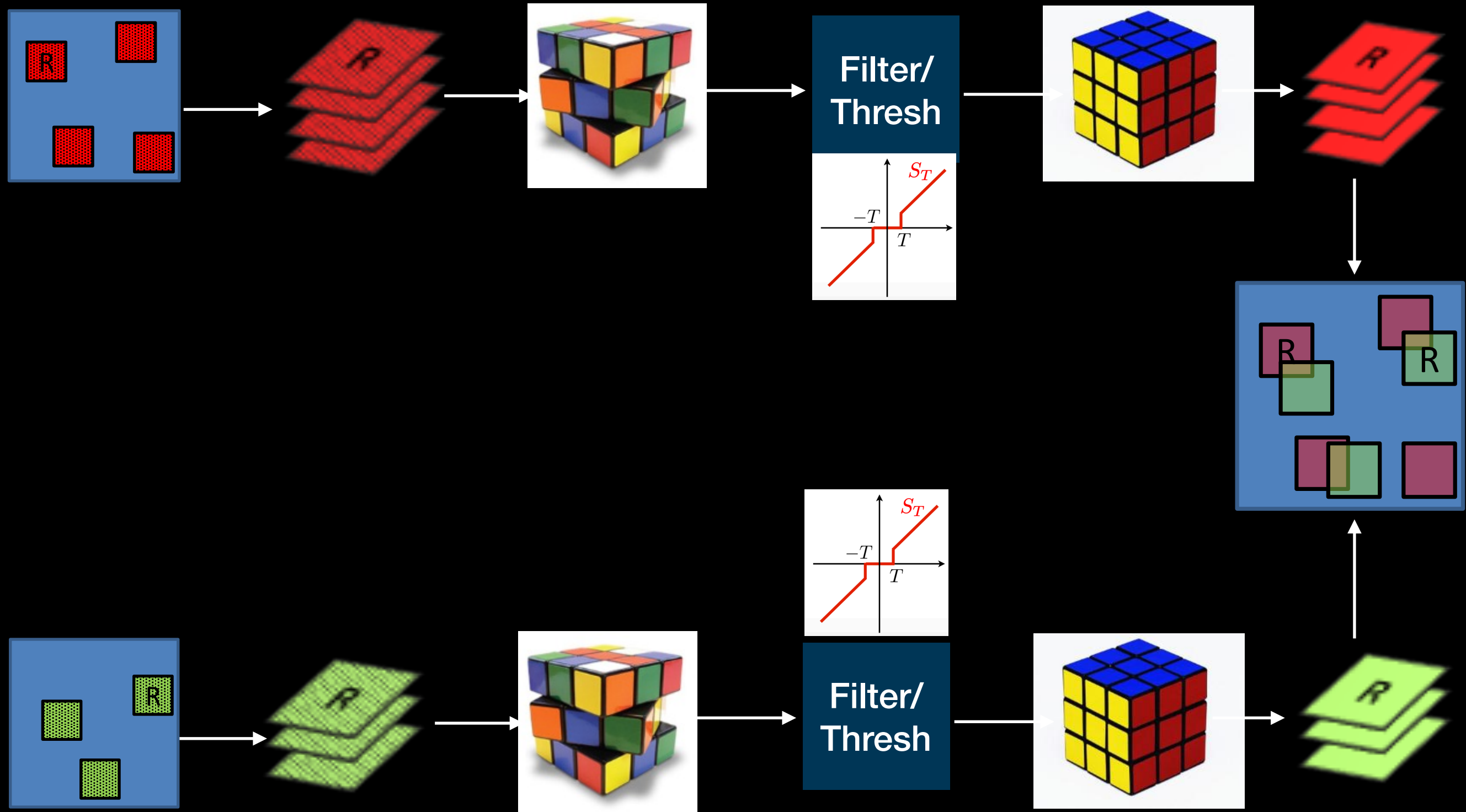


# Collaborative filtering

- Use hard thresholding/Wiener filter in the transform domain
- Each patch in the group gets a denoised estimate
- Unlike in NLM, where only the central pixel got the estimate



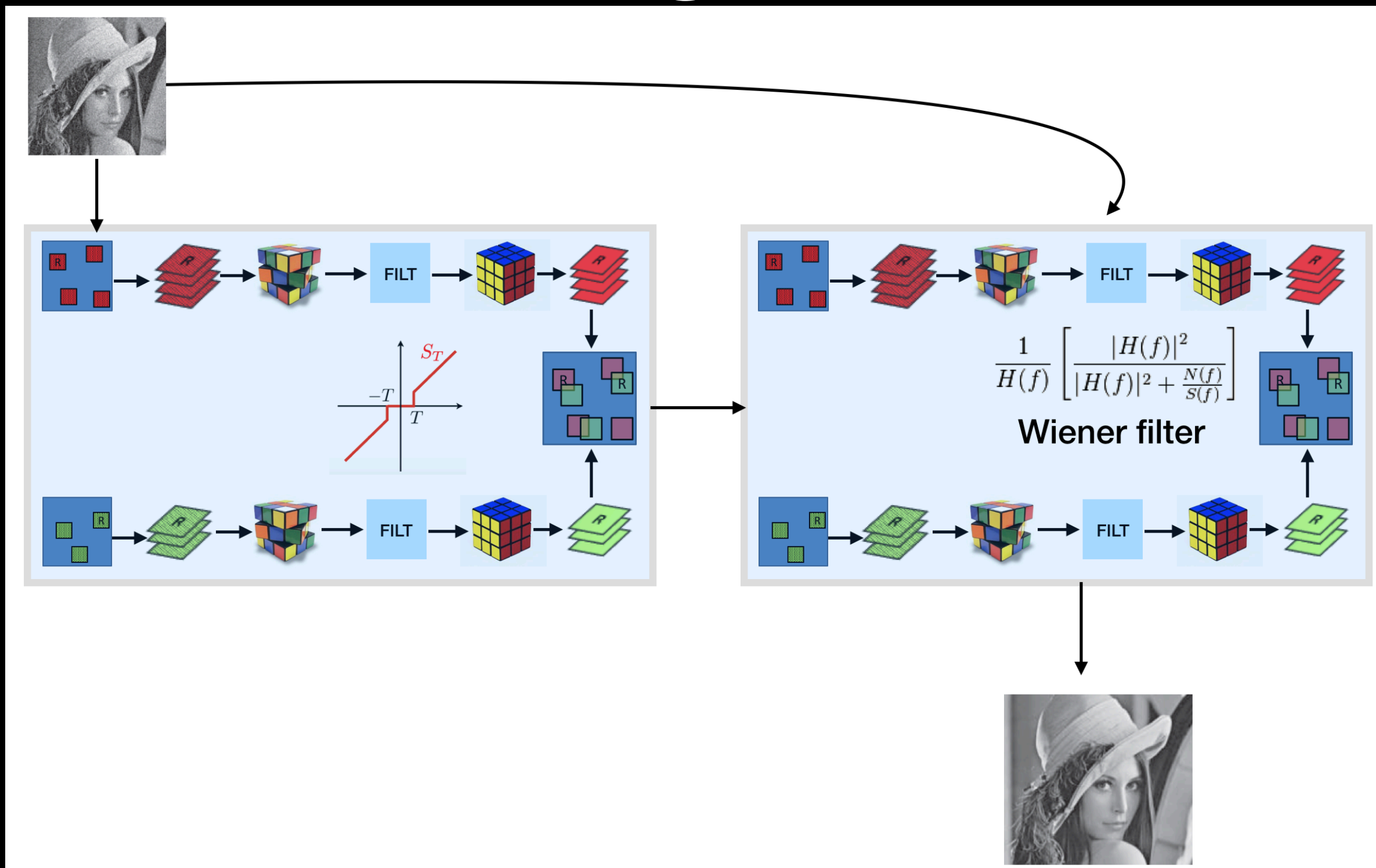
# Multiple BM3D estimates



# Fusion

- Each pixel gets multiple estimates from multiple groups.
- Naive approach: average all estimates of each pixel.
- Problem: not all patches are reliable.
- Suggestion: give higher weights to more reliable estimates.
- Use weights proportional to:
  - $1 / \text{no. of non-zero coefficients}$  (hard thresholding)
  - $1 / \ell_2$  norm of the filter for (Wiener filter)

# Two stage BM3D



# Summary

- Runs in ~8 seconds for 256x256 images.
- State-of-the-art until 2014-15.
- Extended to videos - BM4D.

