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Edge Preserving Multiscale Image Decomposition with Customized Domain Transform Filters

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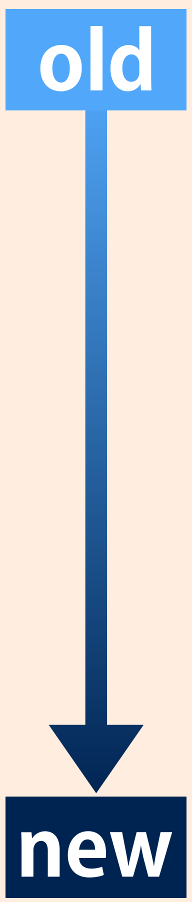
OUTLINE

INTRODUCTION

- edge has important information of signals and images
- many edge preserving smoothing filters have been proposed



- Anisotropic diffusion [1]
- Bilateral filter [2]
- Guided filter [3]
- Weighted least squares [4]
- L0 smoothing [5]
- Domain transform filter [6]

[1] P. Perona and J. Malik, "Scale-space and edge detection using anisotropic diffusion," IEEE Trans. Pattern Anal. Mach. Intel.,vol. 12, no. 7, pp. 629 - 639, Jul. 1990.
[2] C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images," in Proc. IEEE Int. Conf. Computer Vision, pp. 839 - 846, Jan. 1998.
[3] K. He, J. Sun, and X. Tang, "Guided Image Filtering," in Proc. European Conf. Computer Vision, pp. 1-14, 2010.
[4] Z. Farbman, R. Fattal, D. Lischinski and R. Szeliski, "Edge-preserving decompositions for multi-scale tone and detail manipulation," ACM Trans, Graph., vol. 27, no. 3. p67, 2008.
[5] L. Xu, C. Lu, Y. Xu, and J. Jia, "Image smoothing via L0 gradient minimization," ACM Trans. Graph., vol. 30, no. 6, p. 174, Dec. 2011.
[6] E. S. L. Gastal and M. M. Oliveira, "Domain transform for edge-aware image and video processing," in Proc. ACM SIGGRAPH, vol. 30, no. 4, p. 69, 2011.

domain transform filter

input

algorithm

1. domain transform
2. domain transform filter
   - recursive filter
   - normalized convolution
3. inverse domain trasform

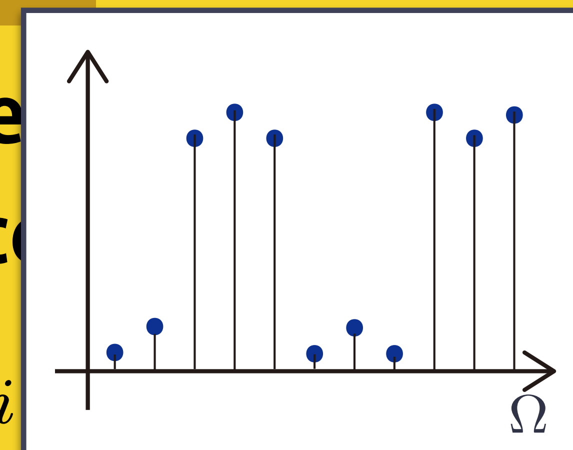
output

input signal

the geode tween

two adjac

t_i

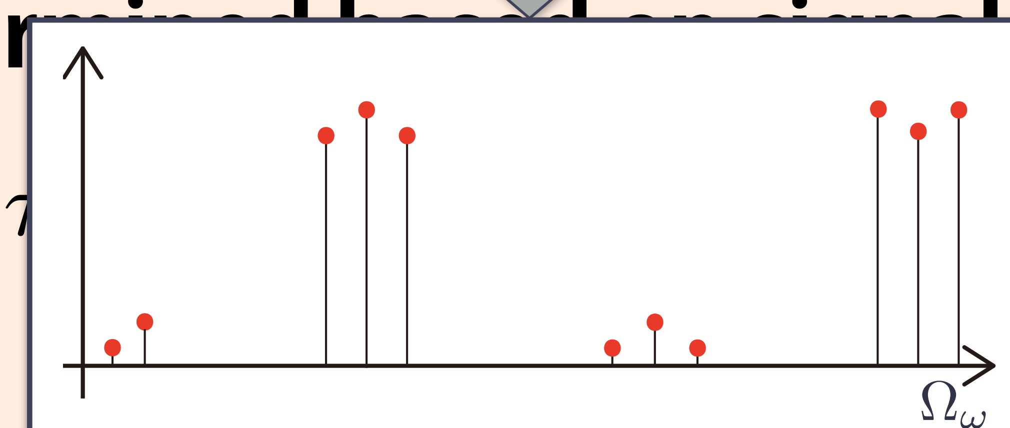


$t_i \in \Omega$

1. Domain Tran rm (DT)

the geodesic di nce is

deter values



$u_i|$

$\tau_i \in \Omega_\omega$

u : signal value

t : coordinate of before DT

τ : coordinate of after DT

Ω : domain of before DT

Ω_ω : domain of after DT

domain transform filter

input

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1. domain transform
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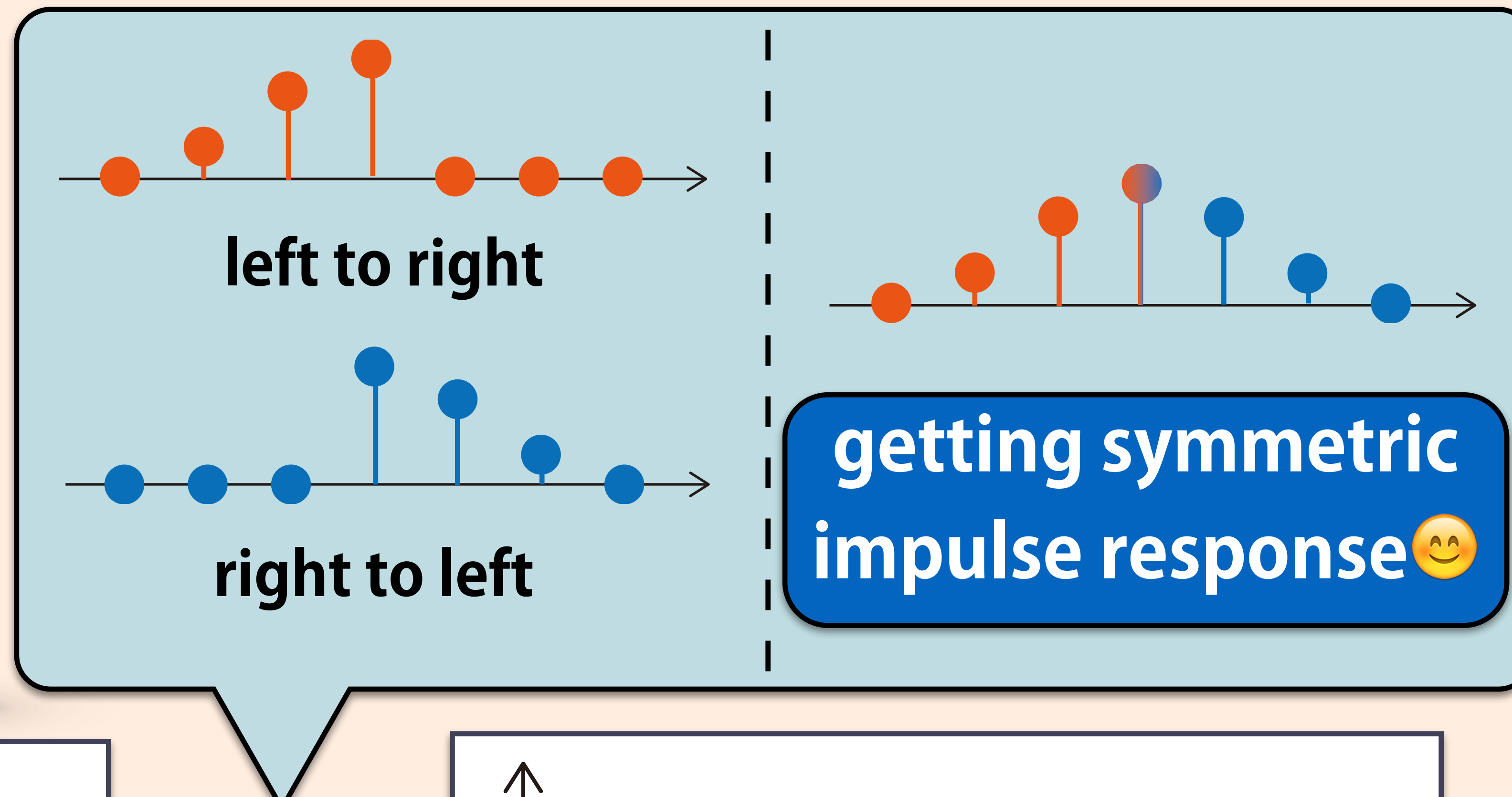
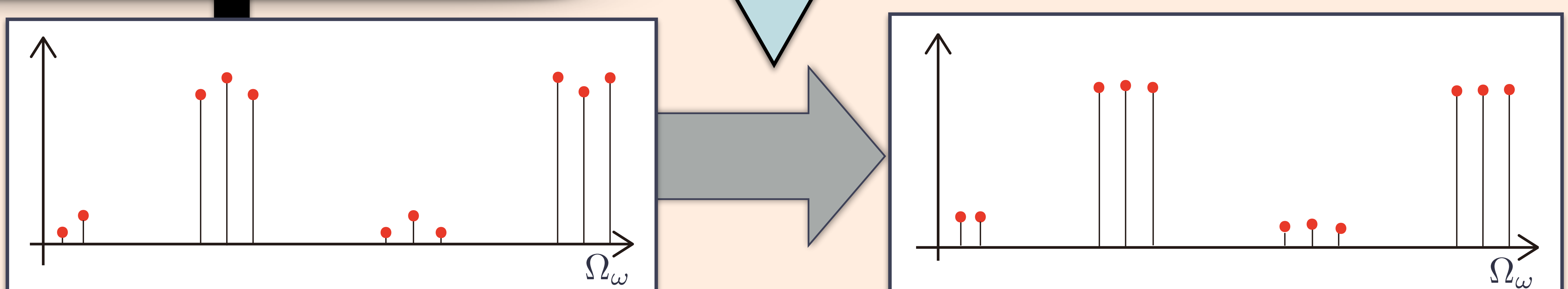
Recursive Filter (RF)

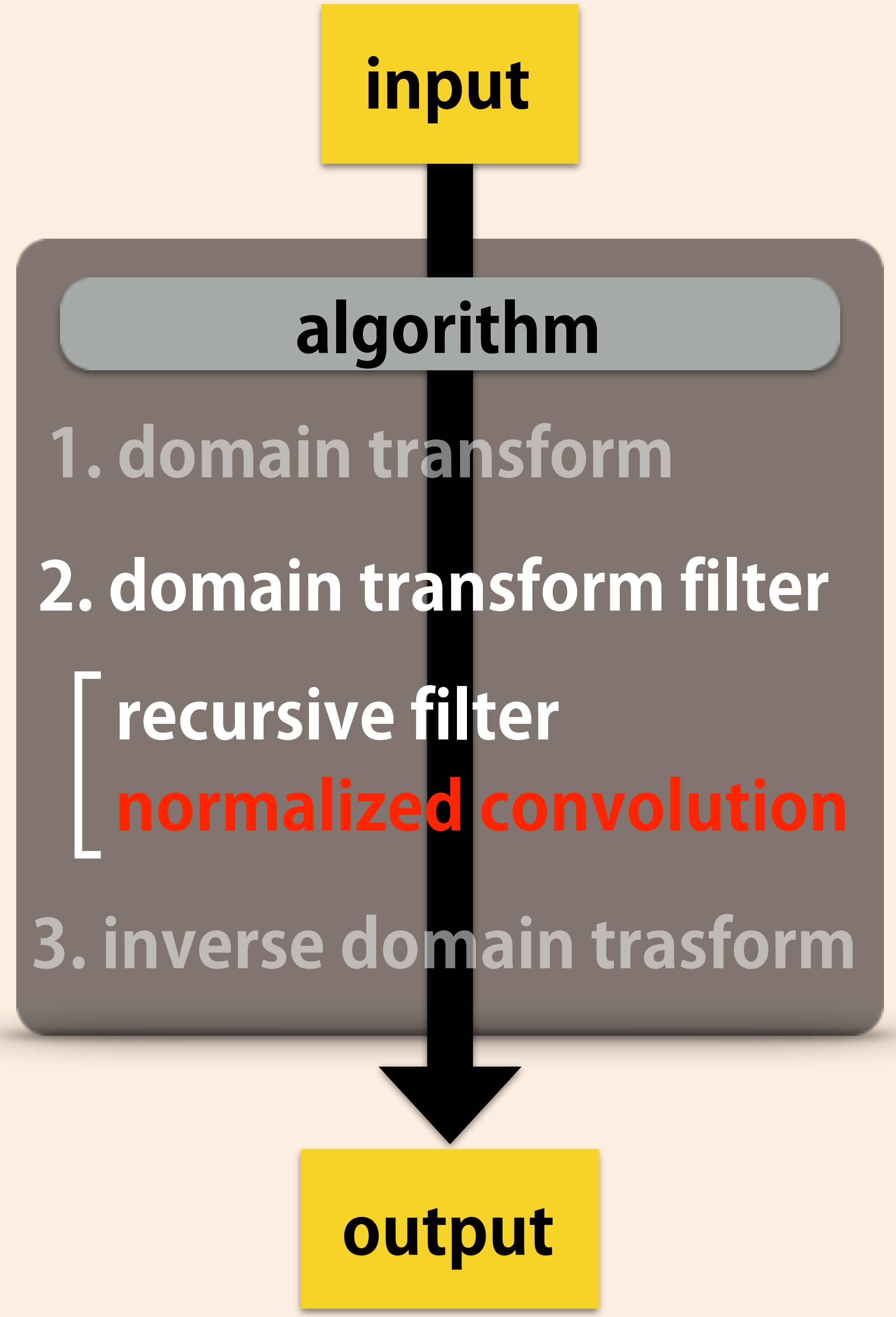
type of filter which reuses output as input in the next step

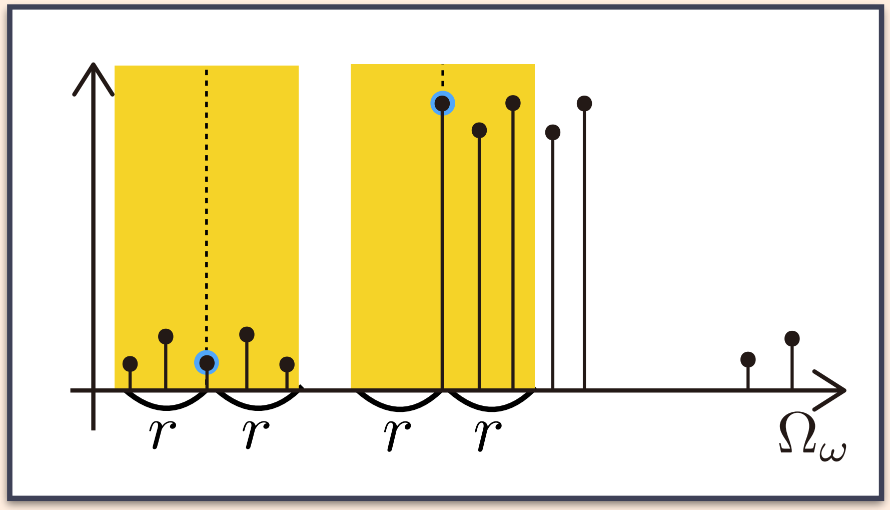
$$y_i = \left(1 - a^{(\tau_i - \tau_{i-1})}\right) u_i + a^{(\tau_i - \tau_{i-1})} y_{i-1}$$





domain transform filter

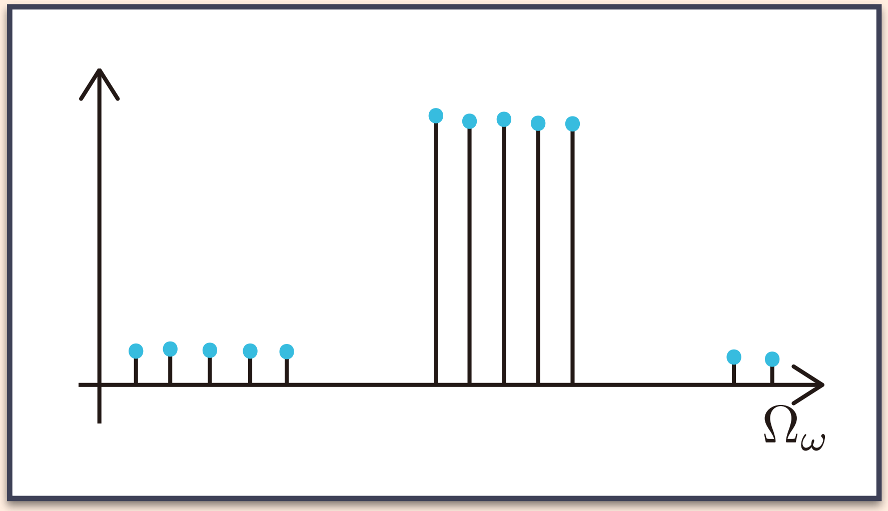




Normalized Convolution (NC)

- **the average of signal is calculated within r from τ_i in Ω_ω**

$$y_i = \frac{\sum_{k \in \Omega_\omega} \delta\{|\tau_i - \tau_k| \leq r\} u_i}{\sum_{k \in \Omega_\omega} \delta\{|\tau_i - \tau_k| \leq r\}}$$



δ : **boolean function**

domain transform filter

input

algorithm

1. domain transform
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   - recursive filter
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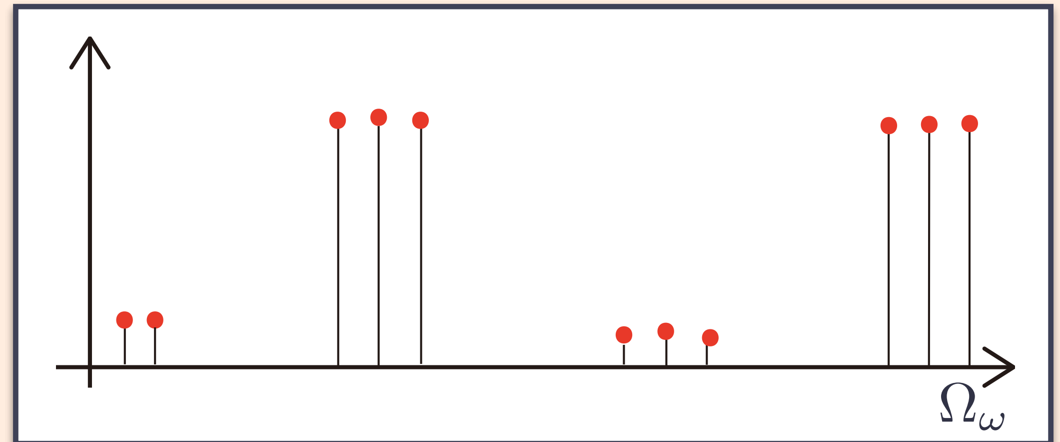
3. inverse domain trasform

output

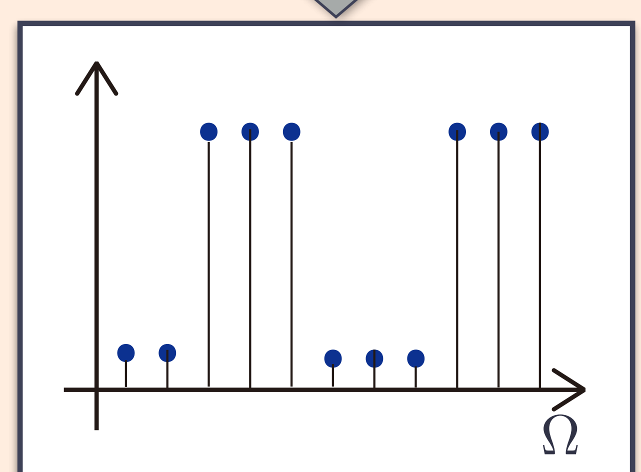


3. inverse domain trasform

output signal

equispaced signal is obtained

$$t_{i+1} - t_i := 1 \qquad t_i \in \Omega$$



OUTLINE

OBJECTIVE

original DTF

good points

- fast edge preserving smoothing method
- can be used to many image processing applications

bad points

- in the case of noisy input...

  it is difficult to calculate appropriate distance between signals

  → the performance becomes bad

⚠ it is highly sensitive to noise ⚠

OBJECTIVE

multiscale DTF

⚠ **it is highly sensitive to noise** ⚠

objective

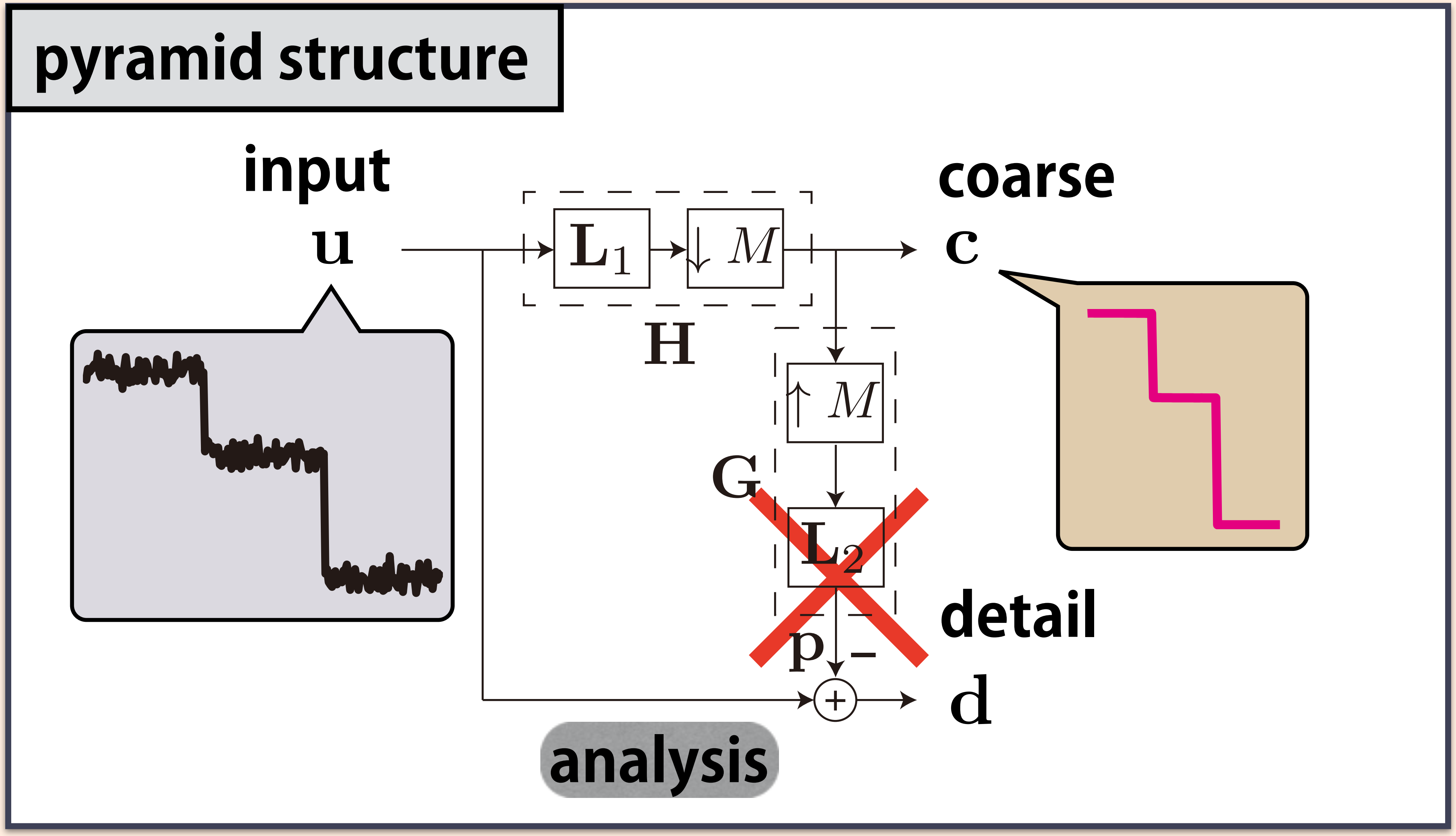
to be robust to noise

multiscale image decomposition method based on the DTF

- uses a similar structure to Laplacian pyramid [6]
- designs optimal filter based on DTF
- realizes several image processing applications

[6] Burt, Peter J., and Edward H. Adelson. "The Laplacian pyramid as a compact image code." IEEE Trans. Commun., on 31.4 (1983): 532-540.

PYRAMID STRUCTURE



■ **objective function :** $\arg\min_{\mathbf{c}}(\|\mathbf{Gc} - \mathbf{Fu}\|_2^2 + \lambda\|\mathbf{Ac}\|_2^2)$

$\mathbf{p}$ **should be similar to the output of DTF**

$\mathbf{c}$ **: piecewise smoothness**

$\mathbf{G}$: lowpass filter $\mathbf{A}$: highpass filter $\mathbf{F}$: domain transform filter (DTF)

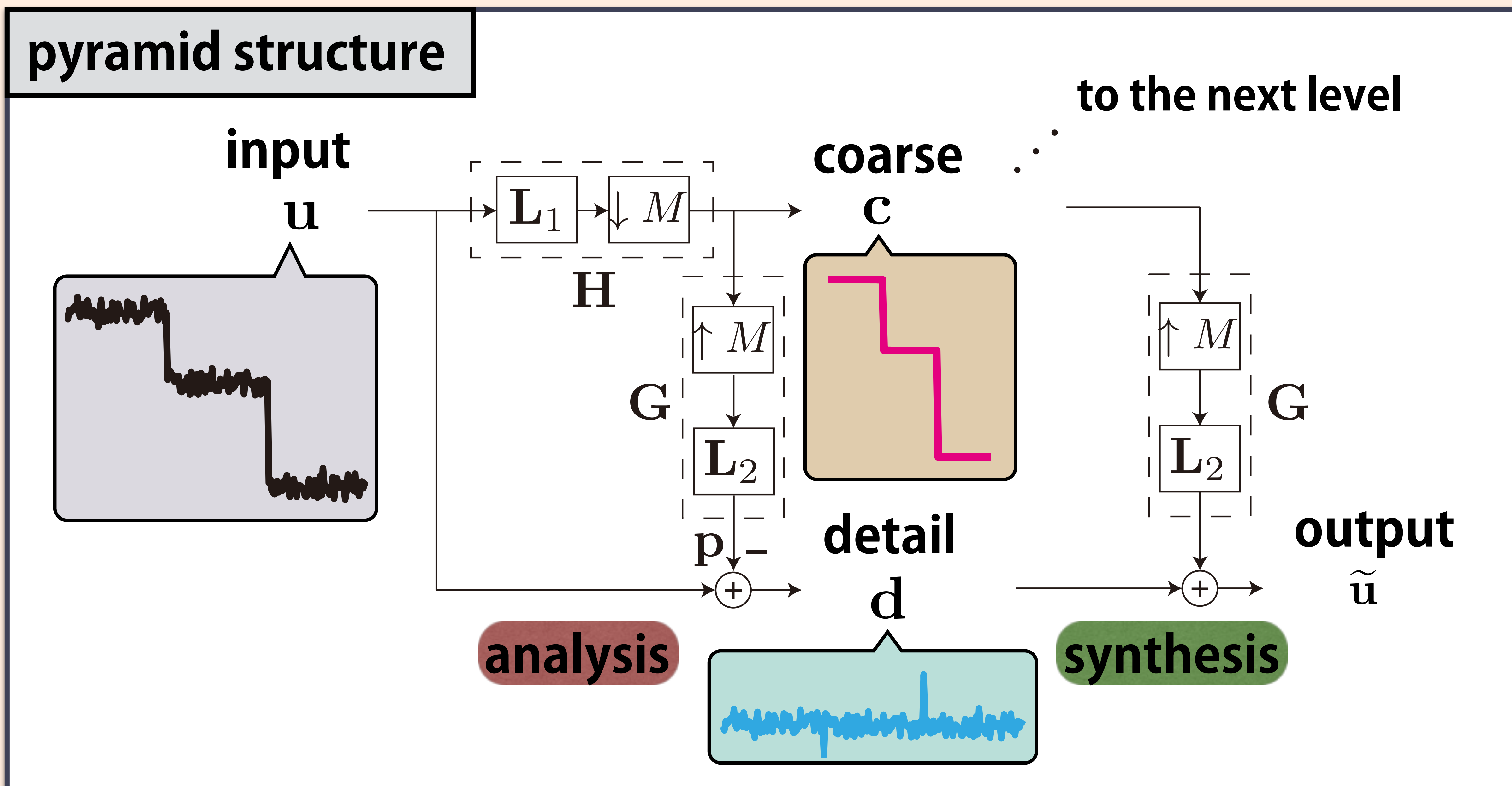
PYRAMID STRUCTURE

- **objective function :** $\arg\min_{\mathbf{c}}(\|\mathbf{Gc}-\mathbf{Fu}\|_2^2+\lambda\|\mathbf{Ac}\|_2^2)$

$$\mathbf{c} = (\mathbf{G}^T\mathbf{G}+\lambda\mathbf{A}^T\mathbf{A})^{-1}\mathbf{G}^T\mathbf{F}\mathbf{u}$$

$$\mathbf{c} = \mathbf{H}\mathbf{u}$$

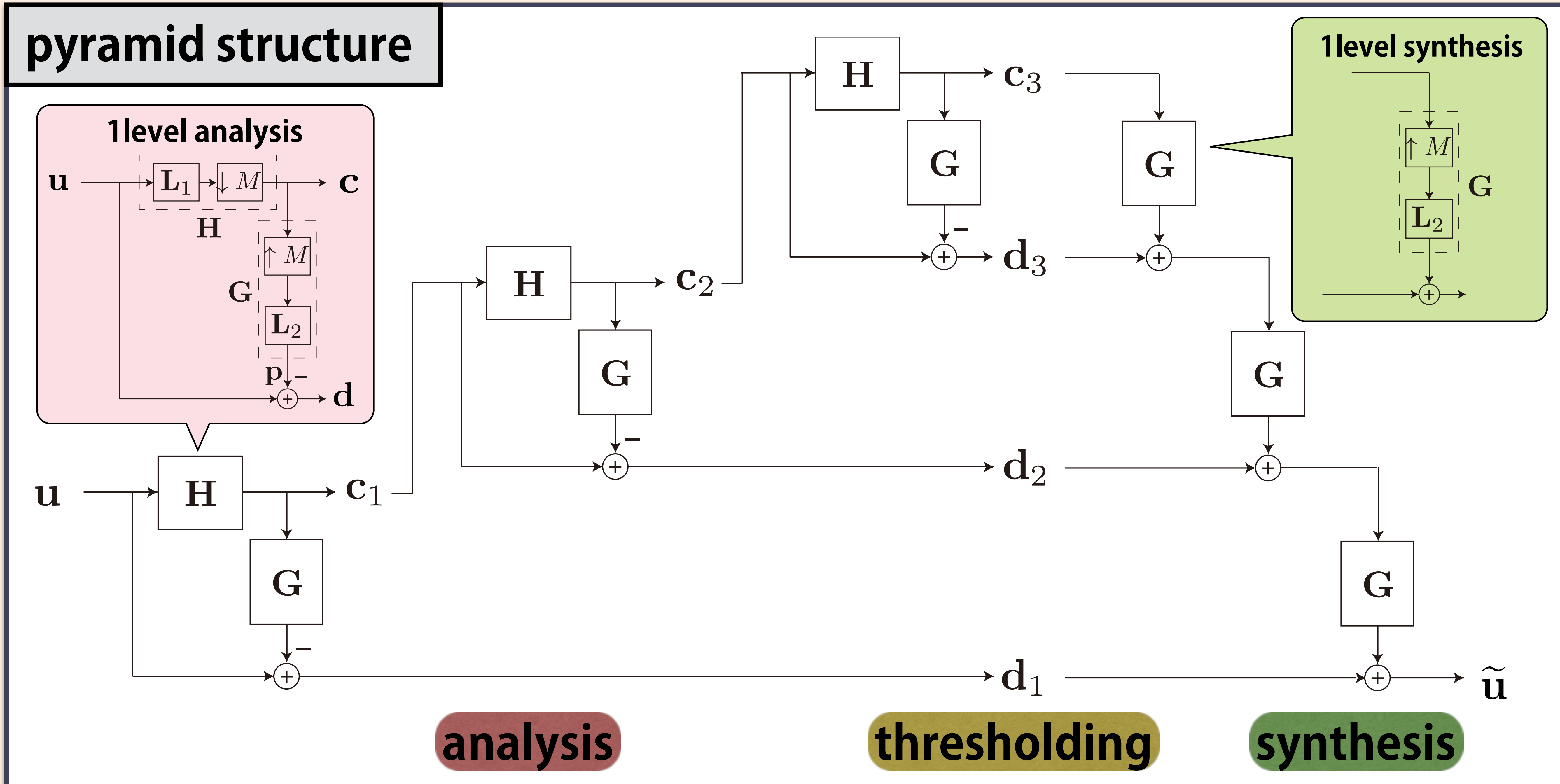
- **optimized filter :** $\mathbf{H} = (\mathbf{G}^T\mathbf{G}+\lambda\mathbf{A}^T\mathbf{A})^{-1}\mathbf{G}^T\mathbf{F}$



PYRAMID STRUCTURE

- **process of the proposed method**

input image → analysis → thresholding → systhesis → output



OUTLINE

EXPERIMENT

applications

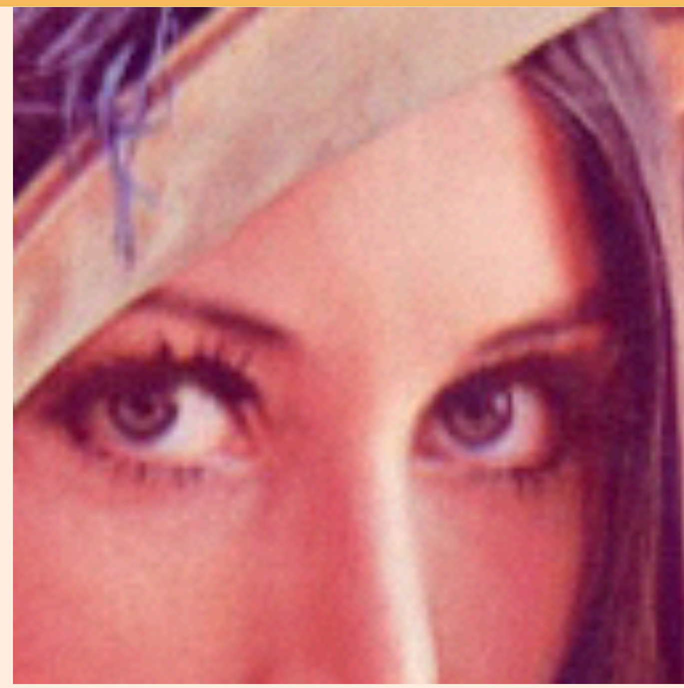
- edge preserving smoothing
  - noise free images
  - noisy images
- detail enhancement

EXPERIMENT

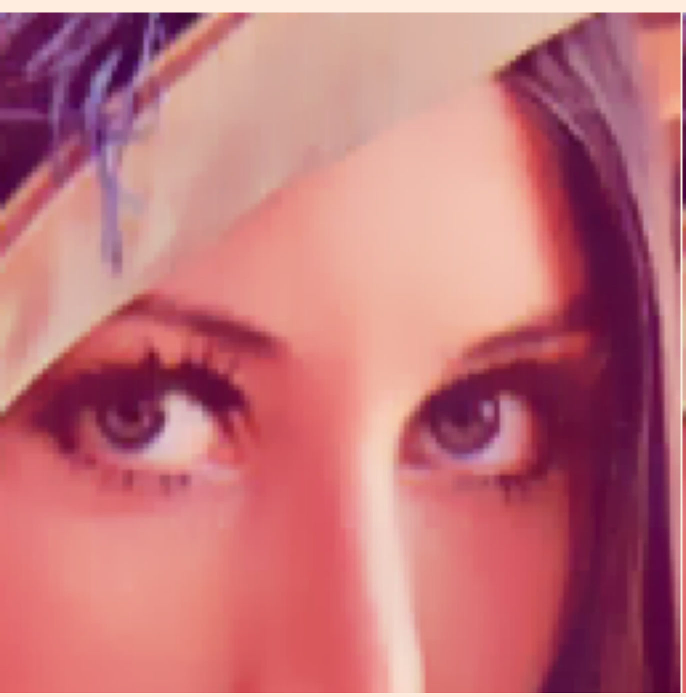
conditions

- conventional method: original DTF
  - DTF: RF / NC
  - parameter sigma: controlling smoothing strength
- proposed method: multiscale DTF
  - DTF: RF / NC
  - parameter: controlling thresholding strength

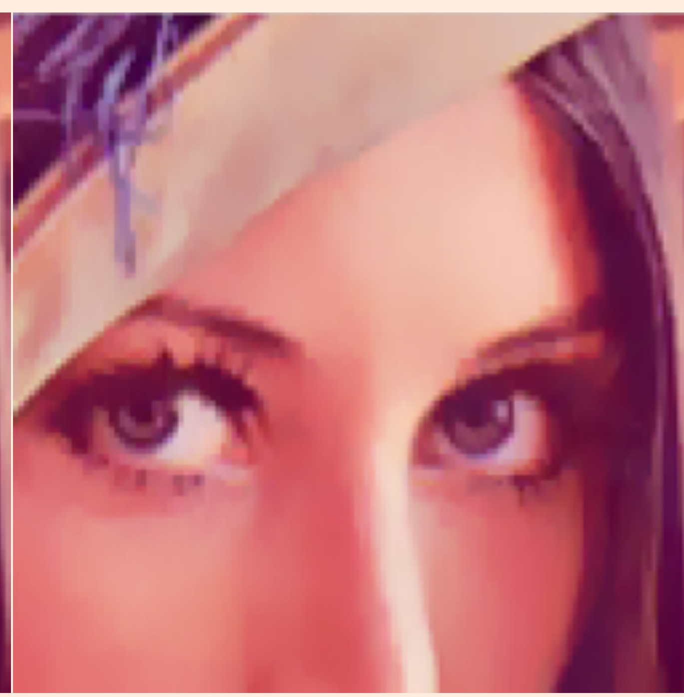
EDGE PRESERVING SMOOTHING



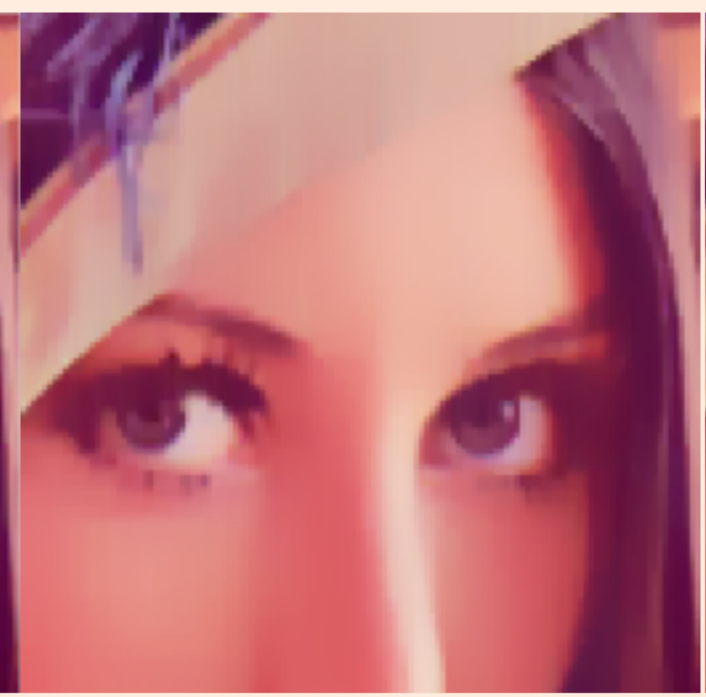
noise-free image



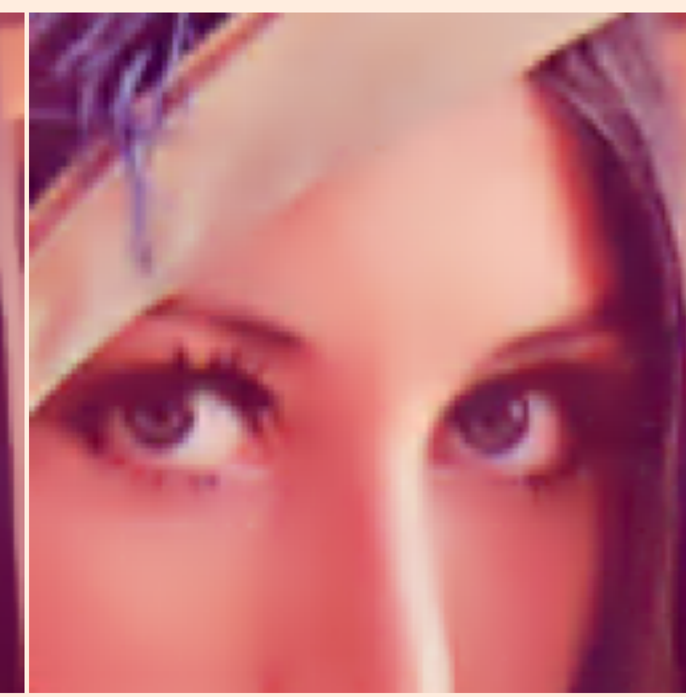
original RF



original NC

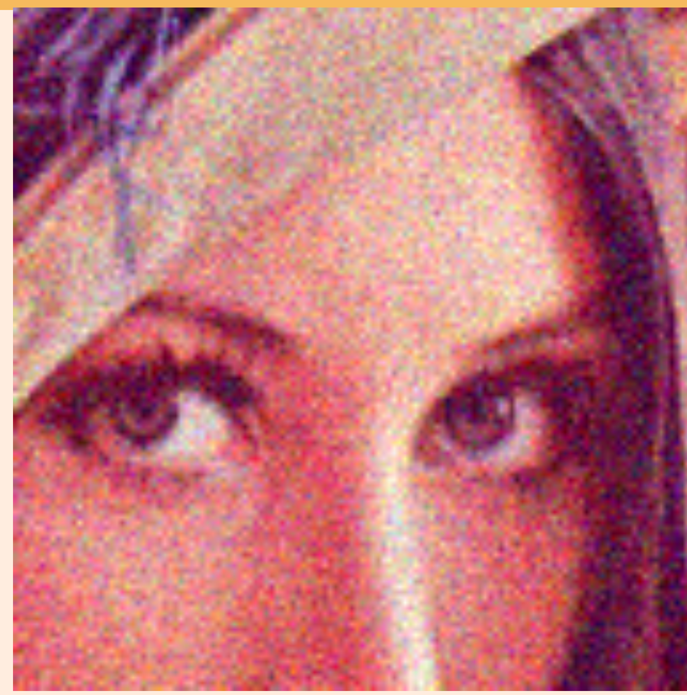


multiscale RF



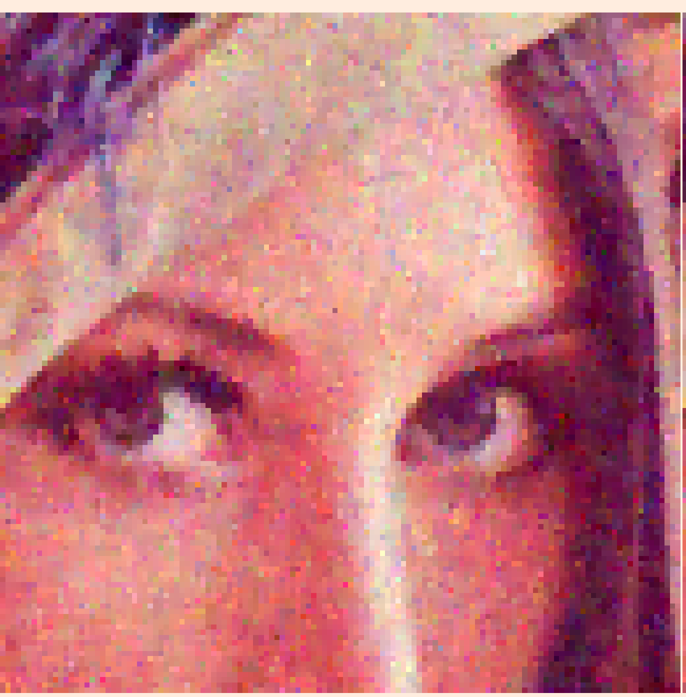
multiscale NC

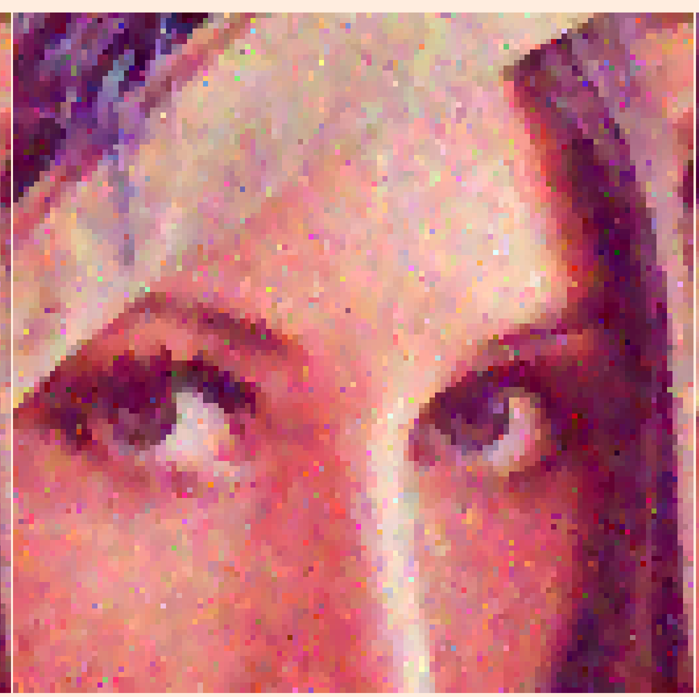
EDGE PRESERVING SMOOTHING

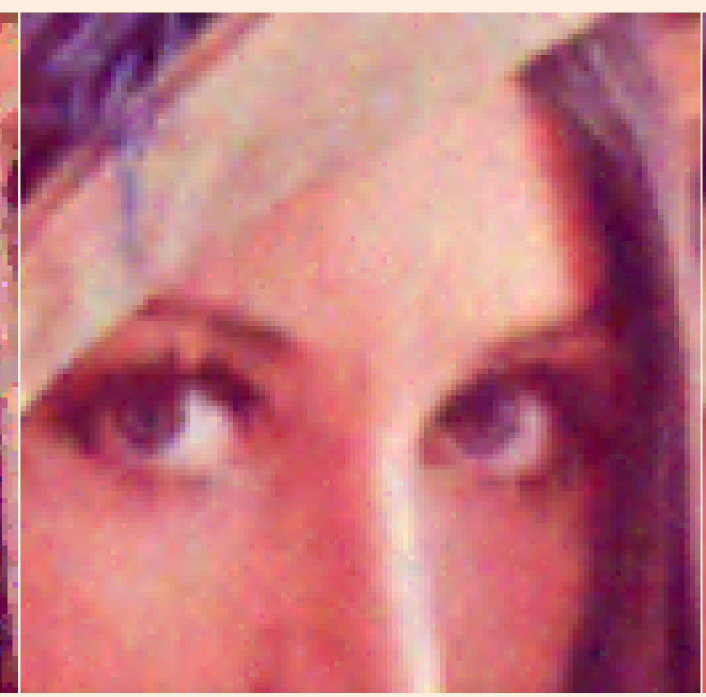


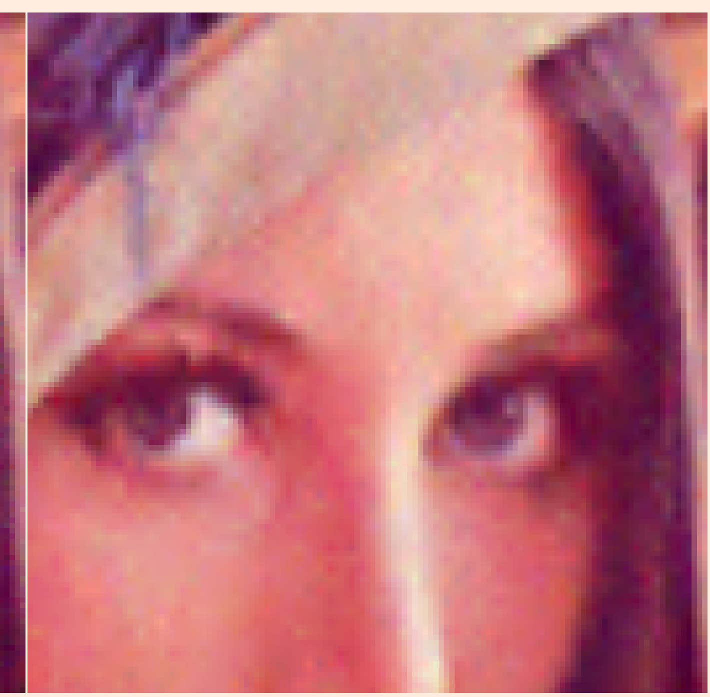
noisy image

$$\sigma = 20$$









original RF
24.00 dB

original NC
23.76 dB

multiscale RF
27.54 dB

multiscale NC
27.11 dB

EDGE PRESERVING SMOOTHING

PSNR Comparison [dB]

method	original RF	original NC	WLS [3]	L0 [2]	multiscal RF	multiscal NC
Pepper	24.00	23.76	26.45	27.13	27.54	27.11
Lena	25.68	25.77	28.34	27.12	28.58	29.06
House	26.62	26.41	28.34	29.61	29.48	29.86
Milkdrop	26.02	26.21	28.12	28.27	28.52	28.83

DETAIL ENHANCEMENT

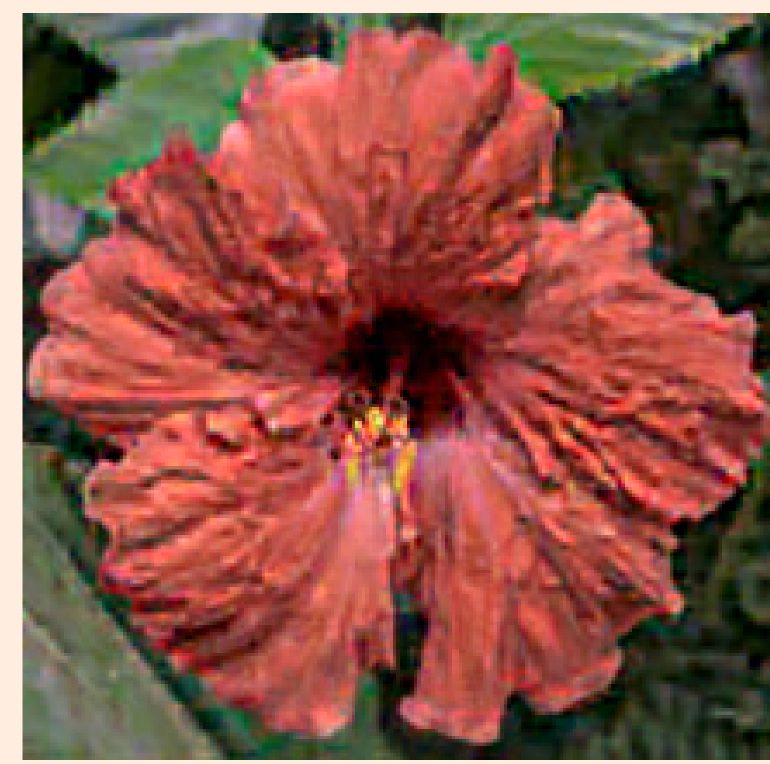
input signal

original NC

1st level

1st/2nd levels

1st/2nd/3rd levels



2nd level

CONCLUSION

objective

design of domain transform robust to noise

proposed method

multiscale image decomposition method
based on the domain transform filter

result

- edge preserving smoothing

→ satisfactory even in the noisy environments

- detail enhancement

→ unique results due to multiscale decomposition

OTHER APPLICATIONS

input image

pencil drawing

stylization

REFERENCE

[1] P. Perona and J. Malik, “Scale-space and edge detection using anisotropic diffusion,” IEEE Trans. Pattern Anal. Mach. Intel.,vol. 12, no. 7, pp. 629–639, Jul. 1990.

[2] C. Tomasi and R. Manduchi, “Bilateral filtering for gray and color images,” in Proc. IEEE Int. Conf. Computer Vision, pp. 839–846, Jan. 1998.

[3] L. Xu, C. Lu, Y. Xu, and J. Jia, “Image smoothing via L0 gradient minimization,” ACM Trans. Graph., vol. 30, no. 6, p. 174, Dec. 2011.

[4] D. Min, S. Choi, J. Lu, B. Ham, K. SohnMin, and M. Do, “Fast global image smoothing based on weighted least squares,” IEEE Trans. Image Process., vol. 23, no. 12, pp. 5638–5653, Dec. 2014.

[5] E. S. L. Gastal and M. M. Oliveira, “Domain transform for edge-aware image and video processing,” in Proc. ACM SIGGRAPH, vol. 30, no. 4, p. 69, Sep. 2011.

[6] Burt, Peter J., and Edward H. Adelson. "The Laplacian pyramid as a compact image code." IEEE Trans. Commun., on 31.4 (1983): 532-540.