Bilateral Filtering

DS-GA 1013 Spring 2021

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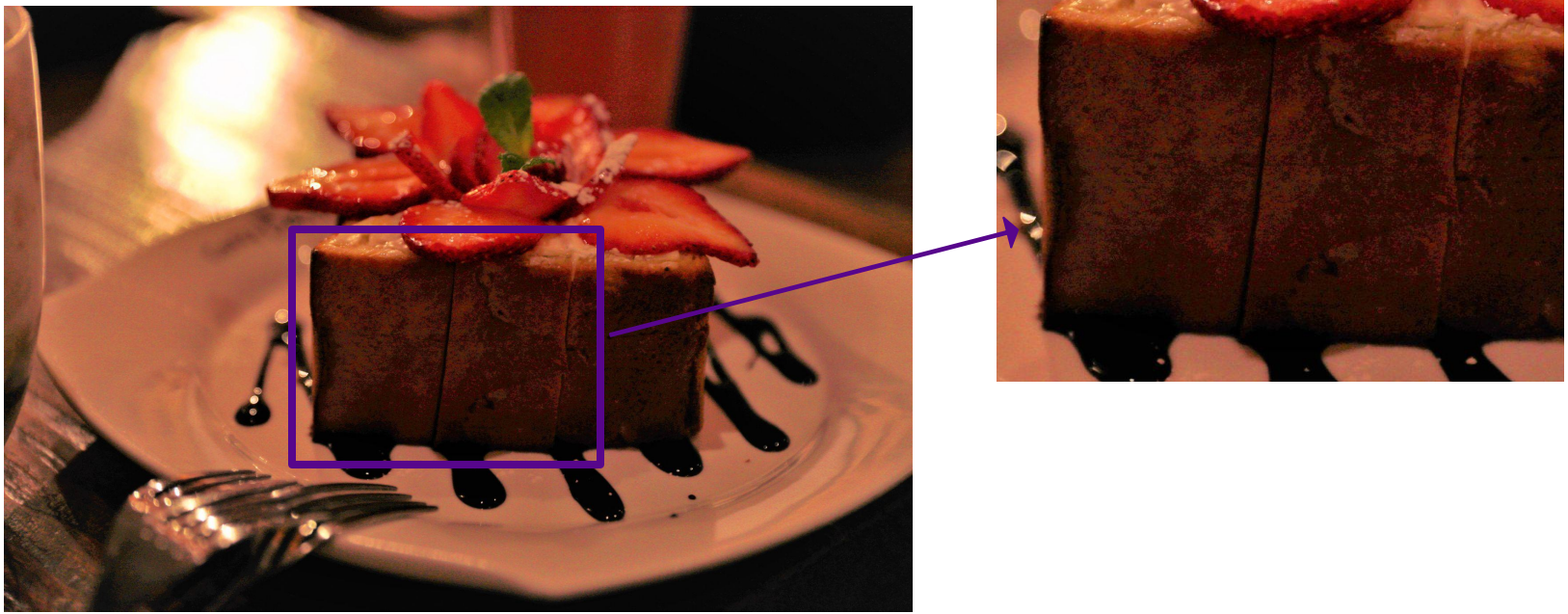
Outline

1. Motivation
2. Definition of Bilateral Filtering
3. Application
4. Hyperparameter Tuning

Why is image filtering important?

1. Produce stylish effects
2. Correct defects and smooth images

Why is image filtering important?



Denoising

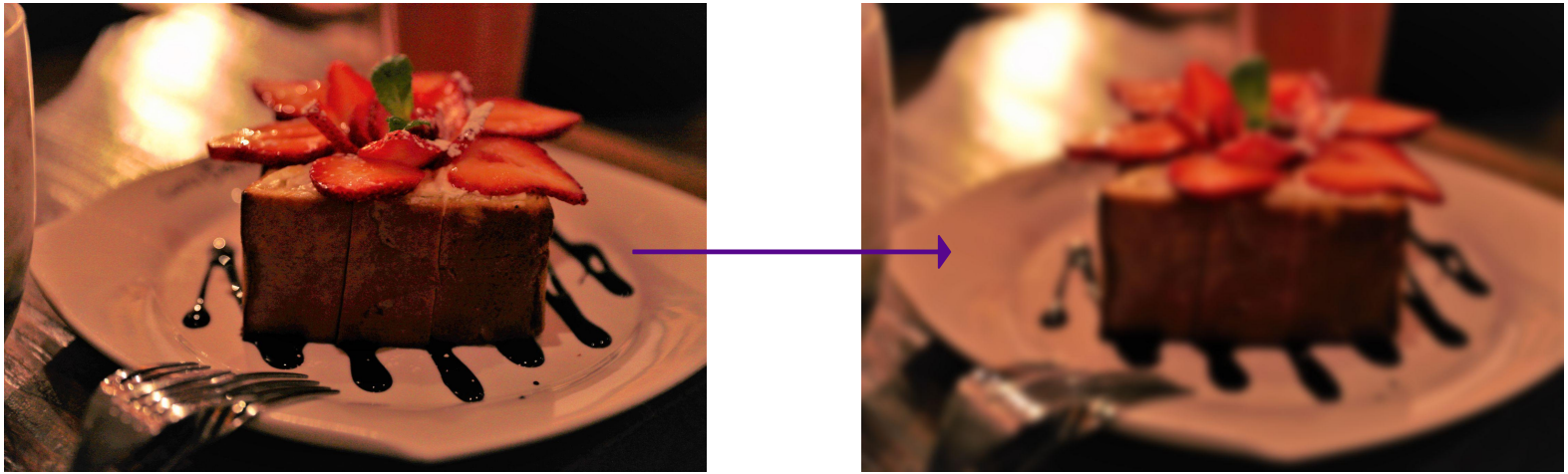
Why is image filtering important?

Tone Mapping

Figure from Durand 02

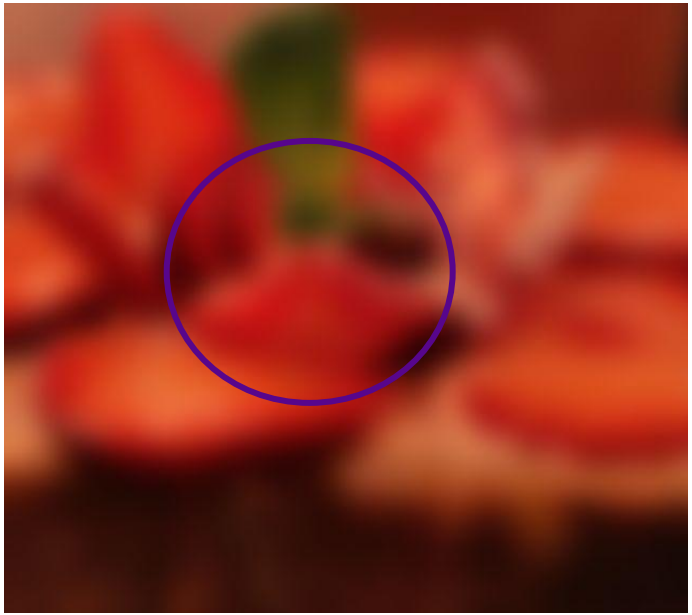
Where does bilateral filtering come from?

Before bilateral filtering, we have Gaussian filtering:



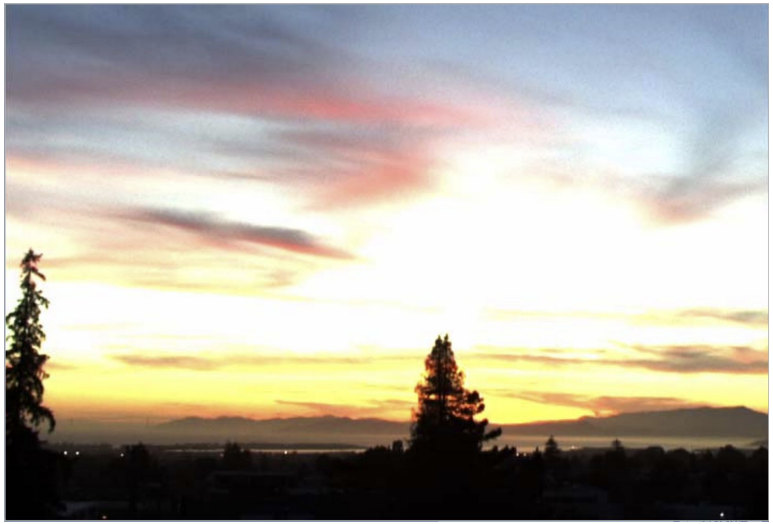
Averaging colors or intensities of nearby pixels in space

Why do we use bilateral filtering over others?



Blurred Edges from Gaussian Filter

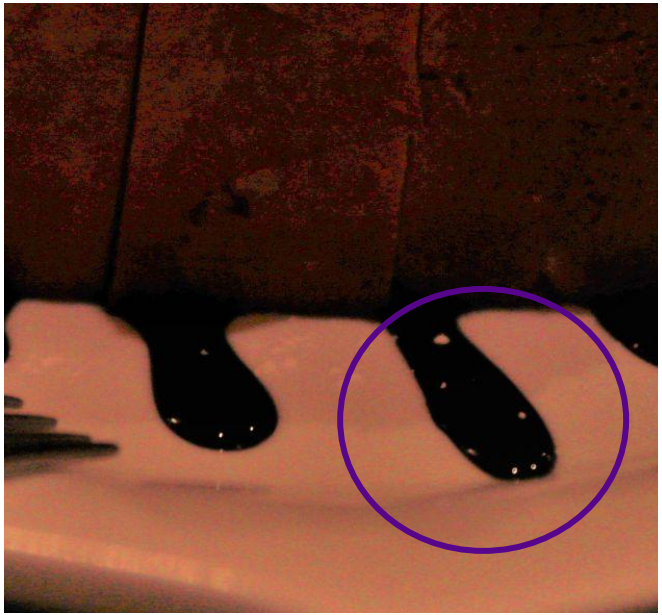
Why do we use bilateral filtering over others?



Halo Artifact from Gaussian Filter

Figure from Durand 02

Why do we use bilateral filtering over others?



Halo Artifact from Gaussian Filter

Definition of Gaussian Filtering

Image = 2D array of pixels (x, y)

Each pixel = intensity (scalar) in gray-level image or color (vector) in color image

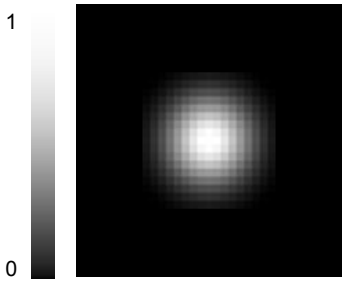
$$GC[I]_p = \sum_{q \in S} G_\sigma(||p - q||) I_q$$

set of pixels

pixel p

pixel q

intensity @ pixel q

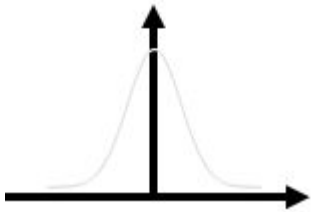


Gaussian distribution (window size determined by **σ**)

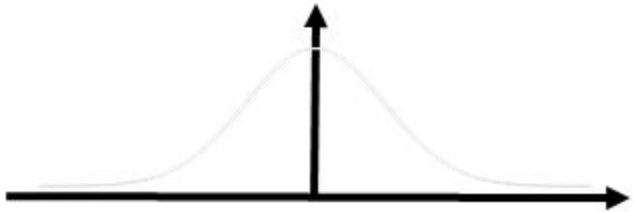
$$G_\sigma(x) = \frac{1}{\sigma\sqrt{2\pi}} exp(\frac{-x^2}{2\sigma^2})$$

Definition of Gaussian Filtering

$$GC[I]_p = \sum_{q \in S} G_\sigma(||p - q||) I_q$$



small σ



large σ

limited smoothing

strong smoothing

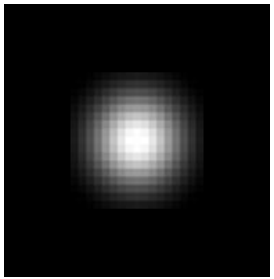
Definition of Bilateral Filtering

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_S}(||p-q||) G_{\sigma_r}(|I_p - I_q|) I_q$$

normalization factor

$$W_p = \sum_{q \in S} G_{\sigma_S}(||p-q||) G_{\sigma_r}(|I_p - I_q|)$$

space difference



intensity range

Definition of Bilateral Filtering

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_S}(||p - q||) G_{\sigma_r}(|I_p - I_q|) I_q$$

σ_S = size of the neighborhood

σ_r = lower boundary of an edge intensity value

Definition of Bilateral Filtering

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_S}(||p-q||) G_{\sigma_r}(|I_p - I_q|) I_q$$

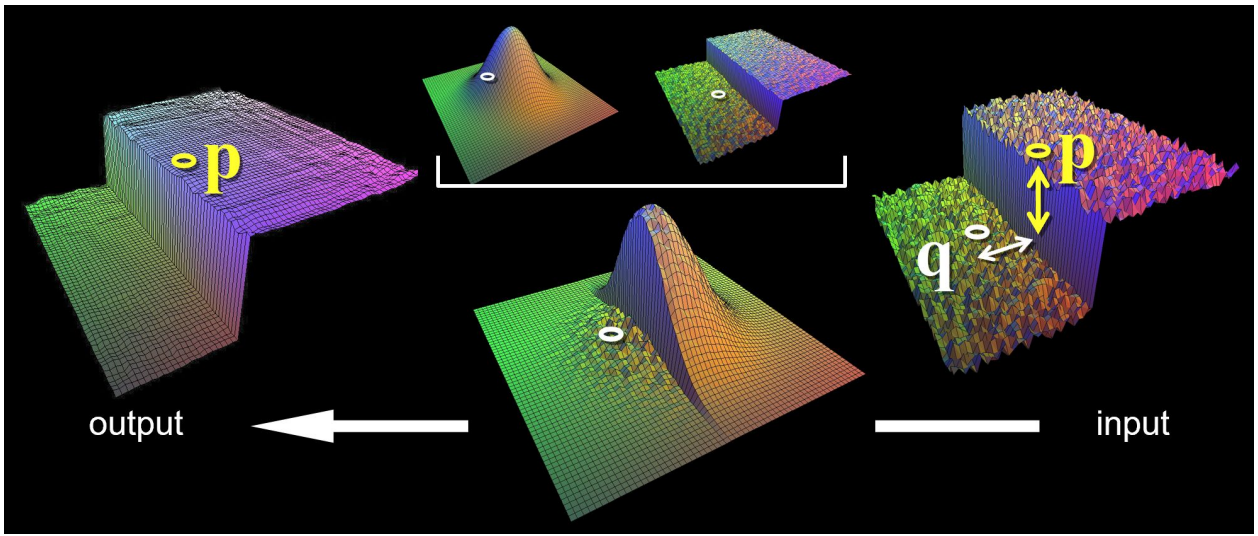


Figure from Durand 02

Definition of Bilateral Filtering

From gray-level image to color image:

Gray-level:

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_S}(||p-q||) G_{\sigma_r}(|I_p - I_q|) I_q$$

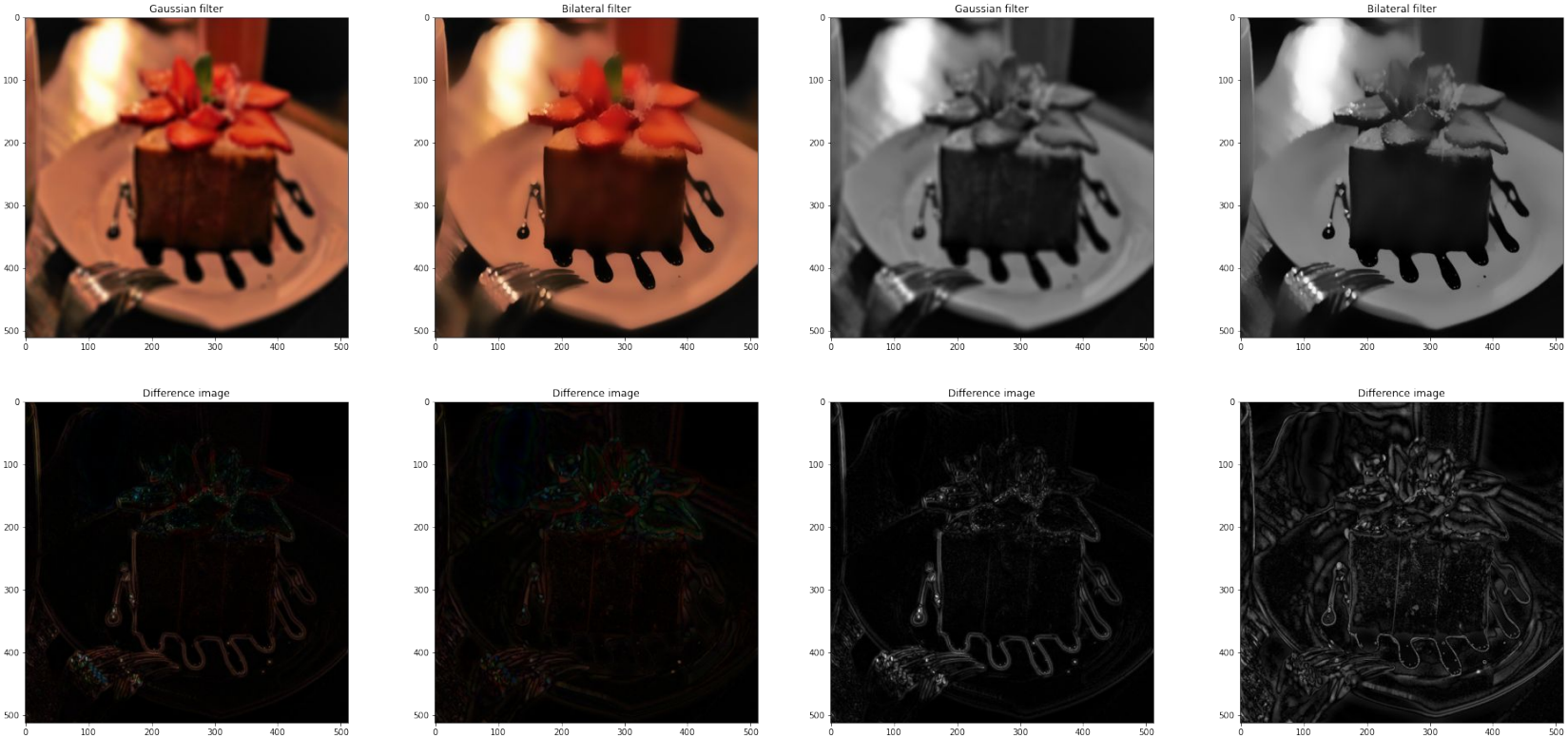
intensity (scalar)

Color:

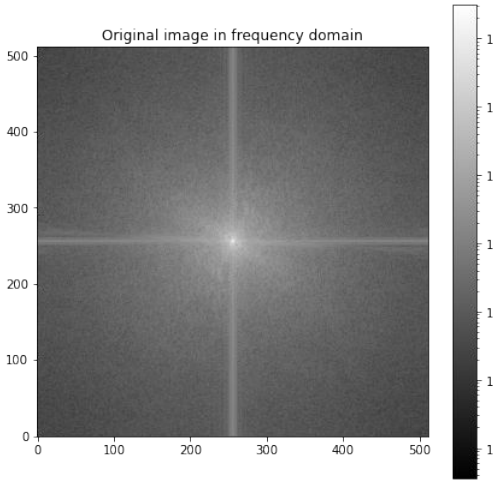
$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_S}(||p-q||) G_{\sigma_r}(||C_p - C_q||) C_q$$

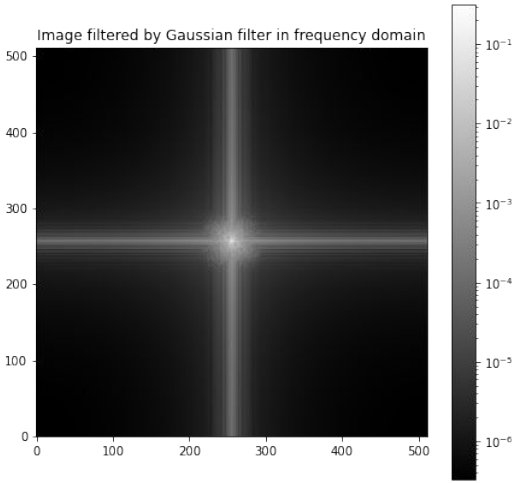
color, e.g. RGB (vector)

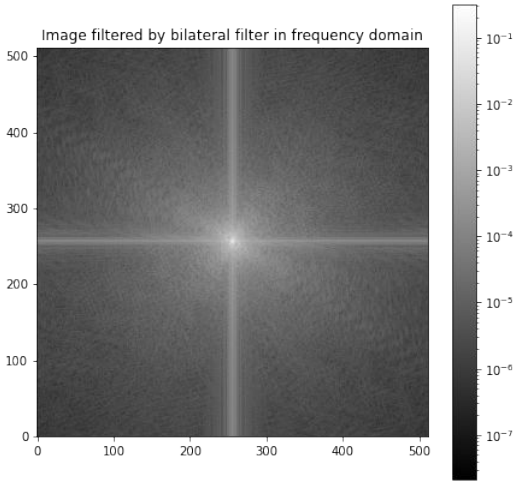
Gaussian vs Bilateral



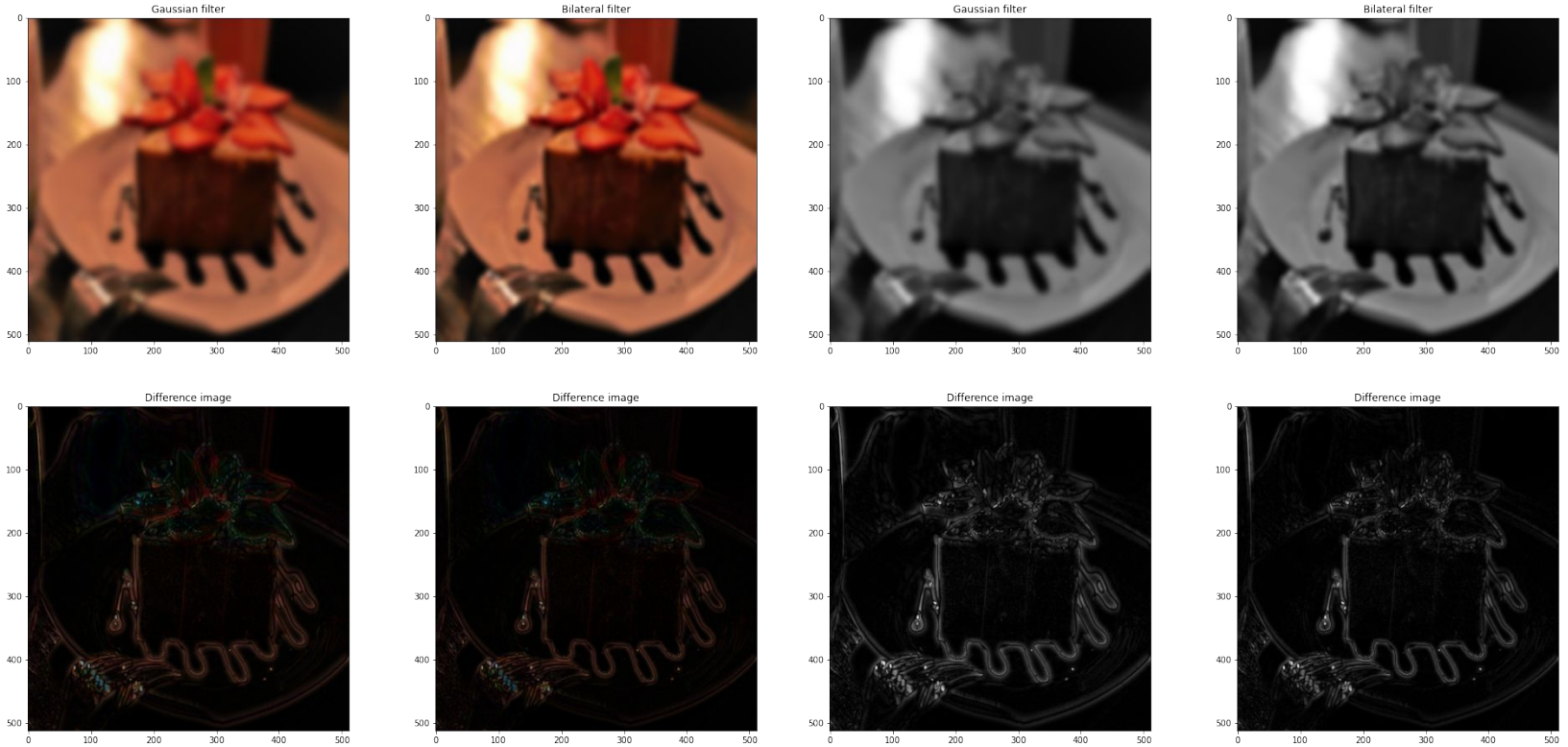
Gaussian vs Bilateral (frequency)



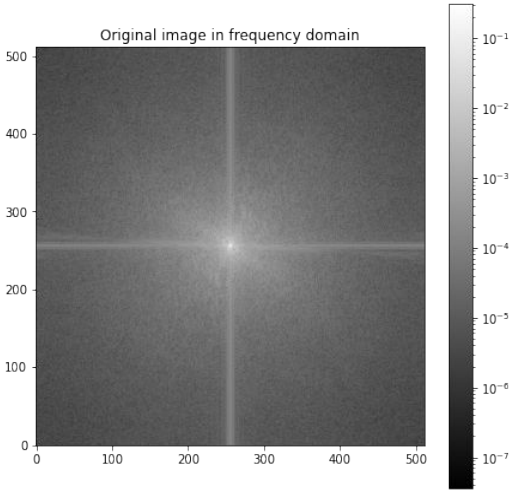


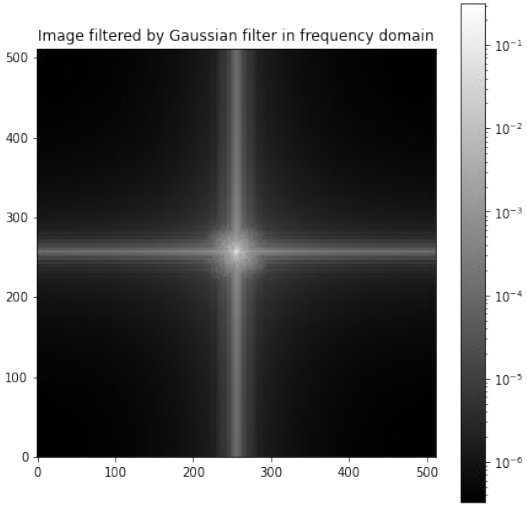


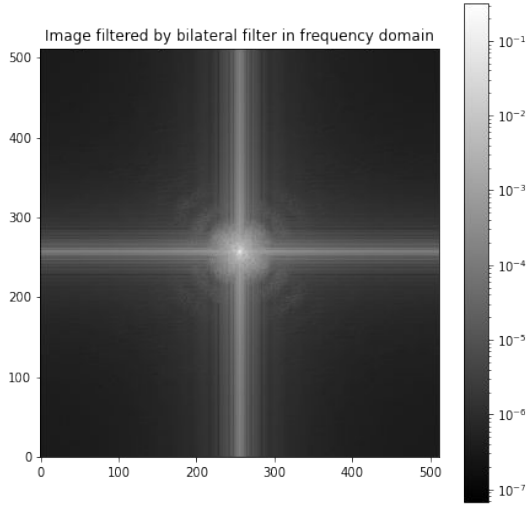
Gaussian vs Bilateral (large σ_r)



Gaussian vs Bilateral (large σ_r , frequency)



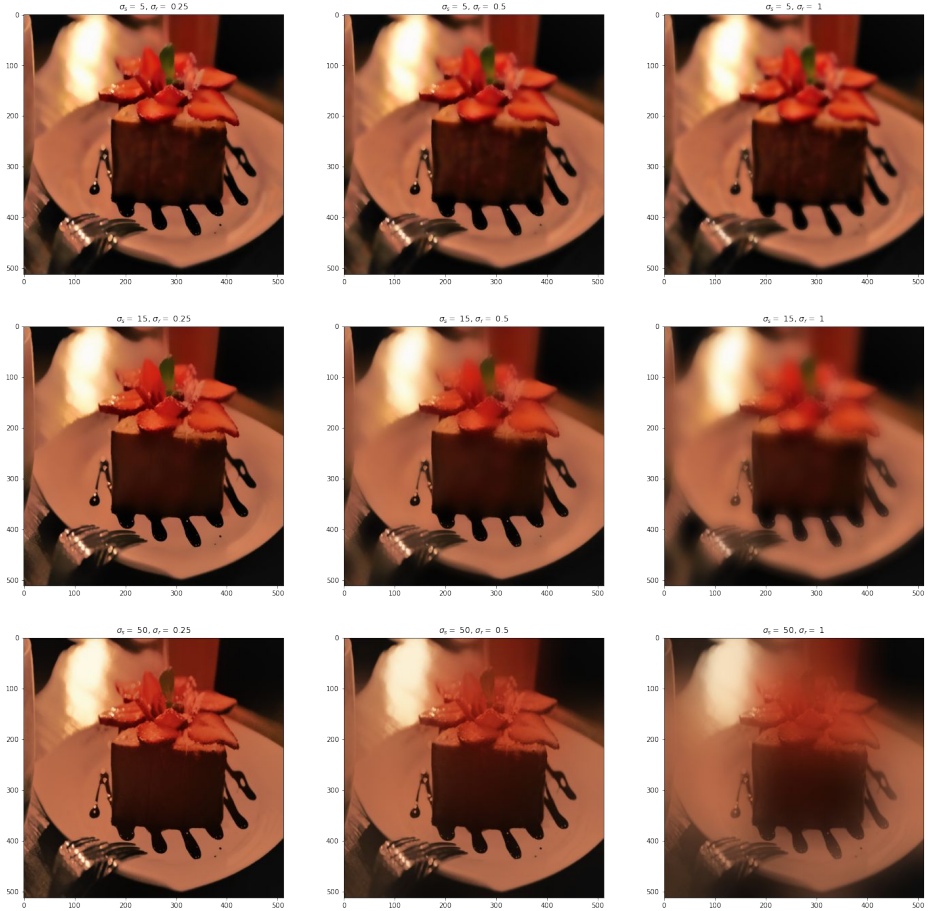




Hyperparameter Tuning

increasing σ_r →

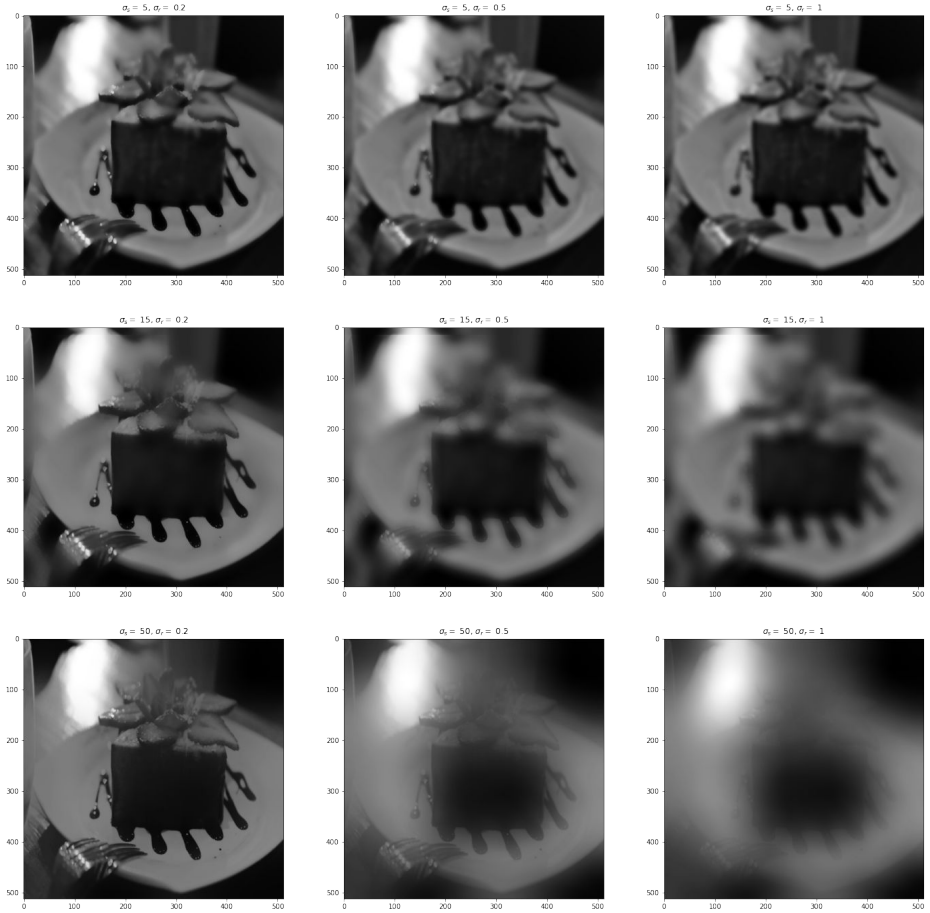
increasing σ_s ↓



Hyperparameter Tuning

increasing σ_r

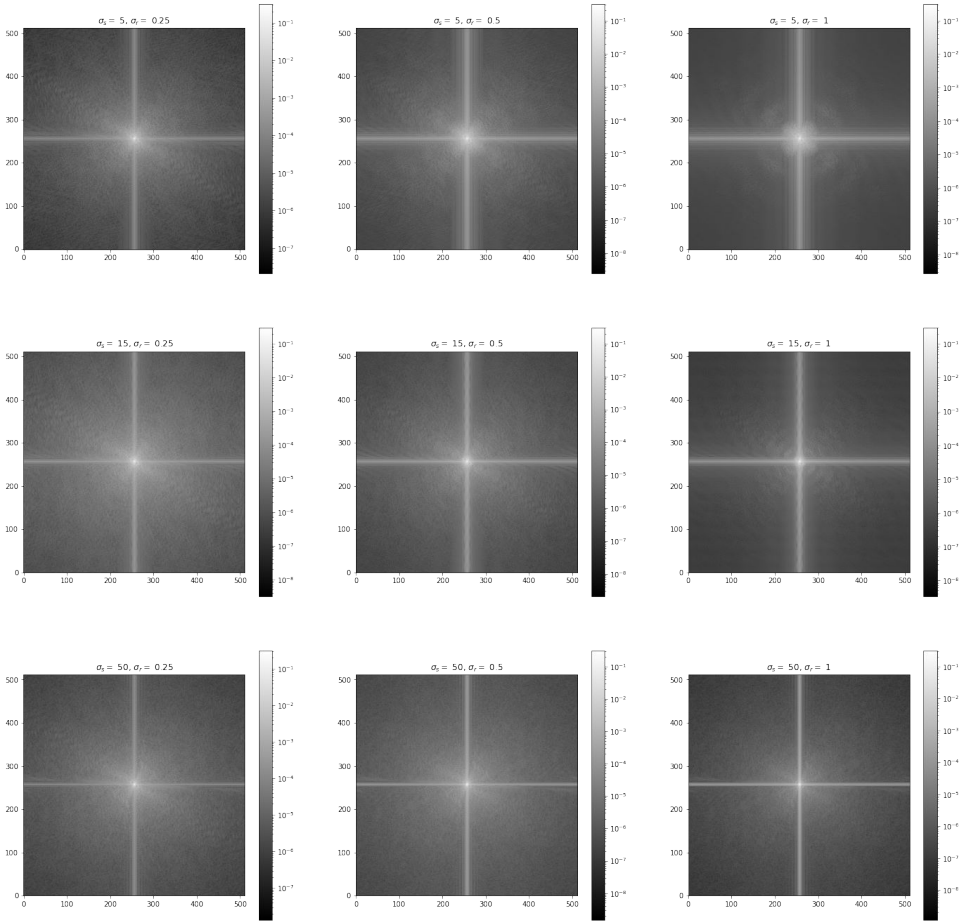
increasing σ_S



Hyperparameter Tuning

increasing σ_r

increasing σ_S



Reference

[1] “A Gentle Introduction to Bilateral and Its Applications”. Sylvain Paris, Pierre Kornprobst, Jack Tumblin and Fredo Durand. ACM SIGGRAPH 2008.

[2] Pierre Kornprobst, Jack Tumblin, and Fr´edo Durand. “Bilateral Filtering: Theory and Applications”.In:Foundations and Trends in Computer Graphics and Vision 4 (Jan. 2009), pp. 1–74